Miscellaneous Paper EL-93-1
March 1993

US Army Corps of Engineers
Waterways Experiment Station

Long-Term Management Strategy for Dredged Material Disposal for Naval Weapons Station, Yorktown, Yorktown, Virginia; Naval Supply Center, Cheatham Annex, Williamsburg, Virginia; and Naval Amphibious Base, Little Creek, Norfolk, Virginia

Phase II: Formulation of Alternatives

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Final report

Approved for public release; distribution is unlimited

Prepared for U.S. Navy, Atlantic Division
Naval Facilities Engineering Command
Norfolk, VA 23511-6287

PREFACE

The work described herein was conducted by the Environmental Laboratory (EL) of the US Army Engineer Waterways Experiment Station (WES). Funding was provided by the US Navy, Atlantic Division, Naval Facilities Engineering Command (LANTNAVFACENGCOM), under Project Orders N61414-89-PO-00020, N0018990P000001, and N0010990WRPW314. The planner-in-charge for LANTNAVFACENGCOM was Mr. Ron Dudley.

This report was written by Dr. Michael R. Palermo, Research Projects Group, Environmental Engineering Division (EED); Mr. Paul A. Zappi, Water Resources Engineering Group, EED; Dr. Tom M. Dillon, and Messrs. Victor A. McFarland, David W. Moore, and Frank Reilly, Contaminant Mobility and Regulatory Criteria Group (CMRCG), Ecosystem Research and Simulation Division (ERSD); and Mr. Tommy E. Myers, Water Supply and Waste Treatment Group (WSWTG), EED, EL, by Drs. Lynn Z. Hales and Norman W. Scheffner, Coastal Processes Branch, Research Division, Coastal Engineering Research Center, WES; and by Dr. Edward L. Thackston, Vanderbilt University. Ms. Carolyn B. Corbett, EED, assisted with data analysis and preparation. The contributions of Mr. Ron Vann, Mr. Steve Powell, and Mr. Terry Getchell of the Dredging Management Branch (DMB), US Army Engineer District, Norfolk (CENAO); John Mazuch, Chief, Cost Engineering Branch, CENAO; and Dr. Thomas D. Wright, CMRCG, ERSD, EL are acknowledged. Technical review of this report was provided by Mr. Norman R. Francingues, Chief, WSWTG, EL; Drs. Wright and Charles R. Lee, CMRCG, EL; Dr. Billy Johnson, Estuaries Division, Hydraulics Laboratory, WES; Messrs. Powell, Getchell, and Vann, CENAO; Mr. Jeff McKee, US Army Engineer District, Baltimore; and Mr. Dudley, LANTNAVFACENGCOM.

This study was conducted under the direct supervision of Dr. Raymond L. Montgomery, Chief, EED, and under the general supervision of Dr. John Harrison, Director, EL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander and Deputy Director was COL Leonard G. Hassell, EN.

This report should be cited as follows:

Palermo, Michael R., et al. 1993. "Long-Term Management Strategy for Dredged Material Disposal for Naval Weapons Station, Yorktown, Yorktown, Virginia; Naval Supply Center, Cheatham Annex, Williamsburg, Virginia; and Naval Amphibious Base, Little Creek, Norfolk, Virginia; Phase II;

Formulation of Alternatives," Miscellaneous Paper EL-93-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
acre-feet	1,233.489	cubic metres
cubic feet per second	0.02831685	cubic metres per second
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
gallons	3.785412	litres
inches	2.54	centimetres
miles (US nautical)	1.852	kilometres
pounds (mass)	0.4535924	kilograms
pounds (force) per square foot	47.88026	pascals
square miles	2.589998	square kilometres
yards	0.9144	metres

LONG-TERM MANAGEMENT STRATEGY FOR DREDGED MATERIAL DISPOSAL FOR NAVAL WEAPONS STATION, YORKTOWN, YORKTOWN, VIRGINIA; NAVAL SUPPLY CENTER, CHEATHAM ANNEX, WILLIAMSBURG, VIRGINIA; AND NAVAL AMPHIBIOUS BASE, LITTLE CREEK, NORFOLK, VIRGINIA

PHASE II: FORMULATION OF ALTERNATIVES

PART I: INTRODUCTION

Background

1. The US Navy, Atlantic Division, Naval Facilities Engineering Command (LANTNAVFACENGCOM), the US Army Engineer District, Norfolk (CENAO), and the US Army Engineer Waterways Experiment Station (WES) are developing a long-term management strategy (LTMS) for disposal of dredged material from the Naval Weapons Station, Yorktown (NWS Yorktown), Yorktown, VA; Naval Supply Center, Cheatham Annex (CAX), Williamsburg, VA; and the Naval Amphibious Base, Little Creek (NAVPHIBASE LCREEK), Norfolk, VA. These facilities are located as shown in Figure 1.

2. The concept for LTMS development is an orderly, sequential process that: (a) identifies dredging quantities and frequencies and performs a preliminary assessment of needs versus the existing/available disposal site capacity; (b) formulates alternatives to offset disposal site or capacity shortfalls; (c) applies detailed screening procedures based on engineering, economic, and environmental considerations to arrive at a preferred alternative(s); (d) develops procedural, administrative, and long-term management plans for LTMS implementation; and (e) provides for periodic review and updating of the LTMS plan to maintain viable long-term navigation (Francingues and Mathis 1990).

3. The conceptual process of developing an LTMS and implementing a long-term management plan (LTMP) for NWS Yorktown, CAX, and NAVPHIBASE LCREEK is presented in the five phases shown in Figure 2. Each phase in Figure 2 consists of a series of steps or essential activities that lead to a certain level of decision-making before continuing on to the next phase. Phase I of the LTMS has been completed (Zappi, Palermo, and LaSalle 1990). This report documents the Phase II effort.

Summary of Phase I Results

4. A detailed description of the LTMS phases and the results of the Phase I effort are given in Zappi, Palermo, and LaSalle (1990). A summary of the results and conclusions from the Phase I effort is given below.

Geographic limits and time frame for LTMS

5. Considering the locations of the facilities and potential disposal areas, the geographic limits for the LTMS should encompass the lower York River and lower Chesapeake Bay. A 50-year disposal capacity was assumed as the time frame for the LTMS.

Dredging requirements

6. Over the 50-year life of this LTMS, the total dredging requirement which must be accommodated is approximately 4,880,000 cu yd.

7. Based on historical dredging records for NWS Yorktown, CAX, and NAVPHIBASE LCREEK, the dredging requirements are assumed as follows:

a. At NWS Yorktown, 200,000 cu yd* of material every 7 years;

b. At CAX, 60,000 cu yd of material every 10 years;

c. At NAVPHIBASE LCREEK, 140,000 cu yd of material every 4 years from the tributaries of Little Creek inlet (NAVPHIBASE LCREEK tributaries) and 300,000 cu yd of material every 10 years from the main Little Creek channel (NAVPHIBASE LCREEK channel).

Material characteristics

8. Previous physical testing showed that sediment from NWS Yorktown, CAX, and NAVPHIBASE LCREEK's tributaries was primarily fine-grained silt or clay, while sediment from the NAVPHIBASE LCREEK's main channel was primarily sand. Limited sediment characterization and water quality testing have been performed in the past to evaluate disposal alternatives.

Environmental resources

9. Environmental resources of concern for this LTMS are those typical of the lower York River and lower Chesapeake Bay. Low-, middle-, and high-elevational marshes, areas of submerged aquatic vegetation, and oyster and clam grounds are areas of special significance. Several threatened or endangered species are found in this area including the bald eagle, three species of sea turtles, and the whorled pogonia.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is provided on page 5.

10. Environmental concerns most often cited for open-water disposal in this area are direct burial of aquatic organisms and suspension of sediments in the water column. Release of contaminants is generally not a major concern.

Disposal Alternatives

11. Disposal alternatives identified as available options during Phase I included open-water, confined, and beneficial uses. The following constraints on available disposal options and/or sites were assumed:

a. Considering the relatively small dredging volumes and the difficulty in designation or selection of a new open-water site, only previously used or presently active open-water sites were considered as potential options.

b. Considering the historical and aesthetic significance of upland areas located adjacent to the prospective dredging areas and the required use of the Naval facilities for base operations, only previously identified confined disposal facility (CDF) sites on Navy facilities' property were considered as available options. In addition, it was assumed that material dredged from a particular facility could only be disposed in a CDF located on that facility.

12. Open-water disposal. There are seven potential open-water sites that may be available for use by NWS Yorktown, CAX, and NAVPHIBASE LCREEK. These sites include the Dam Neck and Norfolk ocean sites and the Naval Channel, Thimble Shoal, York River, Wolf Trap Alternate, and Rappahannock Shoal Alternate sites in lower Chesapeake Bay (Figure 1). Based on the Phase I evaluation, there appeared to be a sufficient capacity remaining at these sites to allow the disposal of the material from NWS Yorktown, CAX, and NAVPHIBASE LCREEK.

13. Confined disposal. There are several sites at NWS Yorktown and NAVPHIBASE LCREEK that have the potential to function as CDF sites for dredged material. However, records did not indicate that potential CDF sites exist at CAX. Finding a suitable CDF site on NWS Yorktown or NAVPHIBASE LCREEK is complicated by various environmental concerns such as the presence of wetlands and spring-fed streams. The maximum capacity of the sites deemed to be available by the Phase I evaluation is approximately 1,042,000 cu yd.

14. Beneficial uses. Beach nourishment has been used in the past for the disposal of material dredged from NAVPHIBASE LCREEK Channel. However, only about one third of the material dredged from NAVPHIBASE LCREEK's main channel has been suitable for beach nourishment. Considering the benefits that are derived from beach nourishment and that some of the material from

NAVPHIBASE LCREEK's main channel is suitable for beach nourishment, this form of disposal should continue. Shoreline disposal for purposes of bank stabilization at CAX seems to be a potential use for material dredged from either NWS Yorktown or CAX, assuming that material characteristics would be suitable for such use.

Comparison of dredging
requirements and disposal resources

15. The total dredging requirement for all three facilities for the 50-year time frame is approximately 4,880,000 cu yd. This volume exceeds the maximum available volumetric capacity (1,042,000 cu yd) of all the prime candidate confined disposal sites. Only a portion of the material at NAVPHIBASE LCREEK is suitable for beach nourishment. Based on these considerations, placement of a significant fraction of the materials from the three facilities at open-water disposal sites must be considered for the long term.

Purpose and Scope of Phase II

16. The purpose of this report is to document Phase II of the LTMS process, the formulation of practicable* alternatives (options) for disposal of dredged material for NWS Yorktown, CAX, and NAVPHIBASE LCREEK. The scope of the Phase II effort included the following:

a. An appropriate forum and a central point of contact for coordination of the LTMS process with appropriate resource agencies and local interest groups was established. The process used by CENAO for coordination of Federal projects was identified as the most appropriate vehicle for this coordination effort.

b. Environmental, engineering, and economic criteria were established for determining practicable dredging and disposal options. Environmental criteria for acceptability of material for open-water disposal under the Marine Protection, Research, and Sanctuaries Act (MPRSA) in accordance with recently developed Corps/US Environmental Protection Agency (EPA) guidelines were especially critical to this LTMS. Other environmental criteria included those for spatial and temporal proximity to ecologically sensitive areas or endangered species, acceptability of material for beach nourishment or other beneficial uses, and decision points for implementation of control measures for contaminated materials. Engineering criteria included

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* The terms practical, feasible, and reasonable have specific meanings in the context of regulations governing disposal of dredged material. For purposes of this report, the term "practicable" is defined as meeting the environmental, engineering, and economic screening criteria developed for this study.

operational limitations on dredging equipment (pumping/haul distances), physical behavior of dredged material at disposal sites, and potential for contaminant transport. Economic criteria involved comparison of costs of available options with previous practices.

c. Environmental and engineering studies necessary to evaluate each dredging and disposal option were performed. These included sediment sampling and characterization, elutriate tests for evaluation of water column effects due to open-water disposal, bioassay and bioaccumulation tests for evaluation of benthic effects at open-water sites, modeling of short-term physical behavior during open-water disposal, modeling long-term physical behavior at open-water sites, settling and consolidation tests to evaluate physical behavior in CDFs, modified elutriate tests for evaluation of CDF effluent water quality, and leachate evaluations for the potential for movement of contaminants into groundwater at CDFs.

d. Alternative dredging techniques and disposal options were identified that met the LTMS study objectives and the environmental, engineering, and economic criteria.

e. The need for further investigations under subsequent phases of the LTMS process was determined and studies were prioritized accordingly, based on value to the project and costs.

PART II: SCREENING CRITERIA FOR DREDGING AND DISPOSAL ALTERNATIVES

Coordination

17. The establishment of an appropriate forum and central point of contact for the LTMS with other Federal and State agencies was an initial task for Phase II development. The Norfolk District has an established process for such coordination in the form of regularly scheduled meetings with all agencies to discuss the status of pending regulatory actions. This process was used as the forum for coordination for this LTMS. Formal presentations of the results of Phase I and scope of Phase II, and a progress report on the Phase II effort were made at the meetings. Such coordination was considered necessary to ensure that comments and concerns of the resource agencies and environmental groups were appropriately considered in the development of the LTMS. This was especially critical in identifying appropriate screening criteria.

18. The agencies participating in the coordination meetings are:

US Army Engineer District, Norfolk
US Environmental Protection Agency, Region III
US Fish and Wildlife Service
National Marine Fisheries Service
Shoreline Erosion Advisory Service
Virginia Marine Resources Commission
Virginia State Water Control Board
Virginia Institute of Marine Science
Virginia Council on the Environment

Regulatory Framework and Management Strategy

19. Because the Phase I results indicated that there is insufficient confined disposal capacity, the assessment of open-water disposal options was considered a critical aspect of this LTMS. Proposed discharges at ocean sites are regulated under the MPRSA (Section 103), while proposed discharges at sites within waters of the United States (which includes the bay sites) are regulated under the Clean Water Act (Section 404). Further, confined disposal effluent discharges are regulated under Section 404. Evaluations for this LTMS were performed under the appropriate regulatory framework established for Sections 103 and 404.

20. All disposal options considered for this LTMS were examined using the Corps Management Strategy for evaluation of potential effects of contaminants (Francingues et al. 1985, 33 CFR 335-338). The consideration of such potential effects must be conducted for regulatory actions in the same manner as for Federal navigation projects (USACE 1985, RGL 85-1 and RGL 90-3). Under the Corps management strategy, each potential contaminant pathway was examined by first considering if there is a potential problem for the option under consideration. If there is a potential problem, the degree of contaminant release or effect was evaluated using technically appropriate testing protocols. Contaminant controls can then be considered to offset potential effects, if required.

Need for Criteria

21. As a part of the Phase II effort, technical screening criteria for dredging and disposal alternatives were developed. In some cases, definitive numerical criteria were possible. In other cases, criteria were defined to determine the comparative practicability of options. Environmental, engineering, and economic criteria were developed. No attempt was made at ranking the relative importance of environmental, engineering, and economic considerations in determining technical practicability. Rather, an option was required to meet all of the criteria to be considered technically practicable. A summary of the practicable criteria is given in Table 1. Descriptions of the criteria are given in the following paragraphs.

Criteria for Open-Water Disposal

Environmental criteria

22. Environmental criteria for open-water disposal options were developed within the framework of Sections 401 and 404, Section 103, and the Corps management strategy. The main considerations in these assessments were the potential for physical impacts to sensitive resources and the acceptability of materials for open-water disposal from the standpoint of contamination. For open-water disposal options, water column and benthic pathways are evaluated to determine if open-water disposal is acceptable. These were evaluated using the most recent bioassay testing and evaluation procedures.

23. <u>Physical impacts on sensitive resources.</u> For in-bay open-water disposal options, potential impacts to sensitive aquatic resources were considered. Large areas of lower Chesapeake Bay are considered potential fisheries. Further, some areas are considered productive areas for submerged aquatic vegetation or oyster or clam grounds (Zappi, Palermo, and LaSalle 1990). In setting a screening criterion for potential effects of such resources, the existence of commercial fisheries leases has historically been considered of most importance by the resource agencies. A criterion was therefore set concerning the existence of commercial leases within 1 mile of open-water sites under consideration. If such a lease existed, the site would be dropped from further consideration. A related criterion for in-bay options was also developed regarding mound stability (i.e., whether the mounded material remains at the site (accumulative site) or migrates from the site due to currents and wave action (dispersive site)). In-bay sites found to be predominantly dispersive were eliminated from consideration. No such criteria regarding potential physical impacts to adjacent resources or mound stability were applicable for the ocean disposal options, because such impacts are considered in the formal site designation process.

24. <u>Suitability of material for open-water disposal.</u> Under regulations implementing the MPRSA and the CWA, the suitability of placement of a given material at an open-water site is evaluated in light of potential effects on the water column and benthic organisms due to sediment contamination. Federal criteria exist for ocean disposal but no pre-existing standards were specified for the State water quality certification process for in-bay disposal. However, it has been common practice to evaluate discharges in estuarine waters using the same, or similar, criteria as are used for ocean sites. Therefore, Federal MPRSA criteria were assumed to be generally applicable for all ocean and bay sites evaluated as a part of this LTMS study.

25. The Federal criteria applied were those specified in the draft MPRSA testing manual (US Environmental Protection Agency/US Army Corps of Engineers 1991). A tiered approach to testing and evaluations is specified in the manual. Potential water column effects are evaluated in light of the Federal acute marine water quality criteria or water column bioassay results, considering initial mixing. Potential benthic effects are evaluated in light of benthic bioassays, considering both potential benthic toxicity and bioaccumulation. The criterion for benthic bioassays is statistically significant toxicity at least 20 percent greater than that of a reference sediment. The

criterion for benthic bioaccumulation is statistically significant bioaccumulation compared to a reference sediment.

Engineering criteria

26. Engineering criteria are associated with the design, construction, and operational practicability of a dredging or disposal alternative. For example, can the operation be accomplished with readily available equipment, are there unusual safety considerations, or is design and construction possible with conventional techniques?

27. The engineering criteria for open-water sites are concerned with limitations on haul distance or placement techniques linked to constraints on equipment capability (e.g., available ocean-going tugs, sea state constraints, limits on navigation accuracy, etc.) Practicable alternatives would be those involving conventional equipment and techniques and safe operating procedures.

Economic criteria

28. No specific criteria for economic practicability were used for this study. However, cost estimates were made to determine if the various options were comparable with the current costs of disposal at the Craney Island site. These cost estimates were developed by the CENAO using standard US Army Corps of Engineers (USACE) cost-estimating techniques. The major differences in costs for open-water options were related to haul distance.

Criteria for Confined Disposal

Environmental criteria

29. Impacts to sensitive resources. Only confined sites considered for past disposal were considered in Phase I of this LTMS. For potential confined disposal sites, the Phase I study indicated that the sensitive resource of most concern is wetlands. If such sites were deemed to have potential effects on wetlands, they were dropped from further consideration.

30. Contaminants. For confined disposal options, potential contaminant pathways include effluent during hydraulic filling, surface runoff, leachate into groundwater, direct uptake by plants and animals, and emissions to air (volatiles). Because the historical data on sediment contamination for these facilities indicated relatively low levels of contamination, the effluent was considered the primary pathway of concern. Since there were no pre-existing Section 401 standards for effluent contaminant concentrations, Federal acute marine water quality criteria were assumed to be applicable for effluent from

CDFs. The Norfolk District also has a self-imposed criterion of 5 g/ℓ total suspended solids in effluents.

Engineering criteria

31. Several engineering criteria were used for confined disposal sites. The criterion for operational practicability was related to the use of hydraulic dredges with direct pipeline transport to confined sites, including any constraints on pumping distance and static head. Additional engineering criteria included site conditions which would allow construction of conventional earth dikes. Any site that had the potential to conflict with other planned land use by the Navy was eliminated from further consideration.

Economic criteria

32. Criteria for economic practicability of confined options were similar to those for the open-water option (i.e., Are costs comparable with the current costs of disposal at the Craney Island facility?). The differences in costs for confined options are caused by differences in the required handling costs and pumping costs. Direct pumping from a pipeline dredge at prospective York River dredging areas to a Yorktown CDF and from NAVPHIBASE LCREEK tributaries to a NAVPHIBASE LCREEK CDF would be economically practicable. Transport by barge and reslurrying for pumping out to the CDF would be required for disposal of York River material at a NAVPHIBASE LCREEK site, and vice versa. This would result in higher costs.

Criteria for Beach Nourishment

33. The only beneficial use alternatives under consideration for the LTMS are beach nourishment with material from the NAVPHIBASE LCREEK channel, and perhaps the use of some material from the York River for shoreline protection. The engineering criteria for acceptance of materials for beach nourishment are based on the material properties of the existing beach material. Medium sand or coarser material is desirable, and the percent fines should not exceed 15 percent. Other factors, such as color of sand, are also considered. Also, only materials with low levels of contamination are considered for beach nourishment. In general, material with proportions similar to the existing beach material is desired.

PART III: SEDIMENT CHARACTERIZATION AND NEED FOR TESTING AND ASSESSMENTS

Description of Prospective Dredging Areas

Naval Weapons Station, Yorktown

34. NWS Yorktown is located in southeastern Virginia in York and James City Counties (see Figure 1). The NWS Yorktown is located about 1.5 miles upstream of Yorktown, VA, on the west bank of the York River. The NWS Yorktown receives, stores, and provides Navy and Marine operating forces with conventional ammunition, missiles, underwater weapons, and special weapons. Dredging at NWS Yorktown is required to maintain a depth of 42 ft below mean low water (mlw) on the outboard side and 18 ft below mlw on the inboard side of Pier R-3. The dredging frequency at NWS Yorktown is assumed to be 200,000 cu yd every 7 years. A site map showing the layout of NWS Yorktown and areas commonly dredged at NWS Yorktown is shown in Figure 3.

Naval Supply Center, Cheatham Annex

35. CAX is located in southeastern Virginia in York County (see Figure 1). The CAX is located about 4.5 miles upstream of Yorktown, VA on the west bank of the York River. The CAX maintains and operates a material handling stock point for receiving, storing, packing, and shipping of material under the direction of the Naval Supply Center, Norfolk, VA. Dredging at CAX is required to maintain a depth of 35 ft below mlw on the north side, 19 ft below mlw on the south side, and 20 ft below mlw on the east side of the supply pier. The dredging frequency at CAX is assumed to be 30,000 cu yd every 5 years. A site map showing the layout of CAX and areas commonly dredged at CAX is shown in Figure 4.

Naval Amphibious Base, Little Creek

36. NAVPHIBASE LCREEK is located in southeastern Virginia on the southern shore of Chesapeake Bay (see Figure 1). The base is located within the city limits of Virginia Beach and Norfolk, VA. Little Creek Inlet consists of Little Creek Channel flowing to the north and Fisherman's, Desert, and Little Creek Coves as tributaries. The NAVPHIBASE LCREEK is the primary amphibious training support base of the US Atlantic Fleet. The CENAO maintains the main NAVPHIBASE LCREEK Channel at a width of 400 ft and a depth of 22 ft below mlw from 2.5 miles out in the Chesapeake Bay to 1 mile into Little Creek Inlet. Maintenance of channel width over 400 ft is the responsibility of NAVPHIBASE LCREEK. The NAVPHIBASE LCREEK and private interests maintain the rest of

Little Creek Inlet. Depths at the piers located in Fisherman's, Desert, and Little Creek Coves range from 10 to 25 ft below mlw. The dredging frequency at NAVPHIBASE LCREEK is assumed to be 140,000 cu yd of material every 4 years from the tributaries and 300,000 cu yd of material every 10 years from the main channel. A site map showing the layout of NAVPHIBASE LCREEK and commonly dredged channel and pier areas at NAVPHIBASE LCREEK is shown in Figure 5.

Sediment, Water, and Soil Sampling

Methodology

37. Sediment and water were collected from the prospective dredging locations at NWS Yorktown, CAX, and NAVPHIBASE LCREEK. Data on the character of sediments at potential open-water sites were available from previous studies at the Norfolk, Dam Neck, Rappahannock Shoal Alternate, and Wolf Trap Alternate sites. However, no data were available for the Thimble Shoal, Naval Channel, and York River disposal sites. Therefore, samples were collected at these sites for this study. Samples were also collected at reference sites in Chesapeake Bay and at locations adjacent to the ocean disposal sites. Soil samples were also taken at potential CDFs at NWS Yorktown and NAVPHIBASE LCREEK. The purpose of the sampling was to characterize the sediments and soils and to obtain samples for additional engineering and environmental tests.

38. In general, the locations of sediment sampling stations were selected to provide representative areal coverage. The total number of samples was limited to approximately 30 because of project cost considerations. The resulting spacing of the sample stations is on the order of 400 ft and is comparable to that used for previous sampling efforts. Water samples were taken at only one location. More detailed information on the sample station coordinates and depths is available (Waterway Surveys and Engineering, Ltd. 1990). The sounding capability of the sampling vessel was used to ensure that shoal material was sampled. Sample depth measurements indicated that none of the sites had shoaled in greater than 2 ft. Therefore, grab samples were satisfactory for obtaining representative samples of the shoaled material.

39. The sampling stations at the Thimble Shoal, Naval Channel, and York River disposal sites were located in the centroid of the site and were considered representative of these areas. Sampling stations were located along the

center, long axis of the Chesapeake Bay and Atlantic Ocean reference sites, and were considered representative of these areas.

40. Either conventional range-azimuth positioning using a theodolite with electronic distance measurement or sounding wheel, automated range-azimuth positioning (Del Norte Rho-Theta System), or Loran-C positioning was used to locate all sampling stations. Loran-C positioning was used in the Chesapeake Bay and Atlantic Ocean.

Naval Weapons Station, Yorktown

41. Sediment sampling. NWS Yorktown sampling stations were selected to represent both the outboard and inboard sides of Pier R-3. A Ponar sediment sampler was used to remove sediment samples from seven locations (NWS-10 to 16) adjacent to Pier R-3 on two separate occasions. Approximately 11 ℓ of sediment from NWS Yorktown was collected on 30 November 1989 for use in physical and chemical analysis. Approximately 25 gal of sediment from NWS Yorktown was collected on 10 April 1990 for use in biological and settling column tests. NWS-11 had to be relocated just southwest of its original location because of a pile driver buoy located at the original location while sampling on 10 April 1990. Sample locations are shown in Figure 6.

42. Upon retrieval, the samples were placed in wooden or plastic containers and subsamples were removed from the center of the samples and placed in the appropriate containers. Sediment subsamples for use in the chemical analysis were placed in two 40-ml and one 500-ml (or two 250-ml) glass containers with Teflon lids. Sediment subsamples for use in the physical analysis were placed in 1-ℓ plastic containers. Sediment subsamples for use in the biological and settling column tests were composited in 5-gal polyethylene buckets. Entrapped air was minimized by filling the sample containers to the top. Sediment subsamples for use in chemical and biological tests were stored on ice and shipped overnight to WES.

43. Water sampling. Approximately 10 ℓ of surface water for chemical analysis and 5 gal for elutriate tests were collected at Pier R-3 on 01 February 1990. The samples were obtained by submerging a 5-gal polyethylene bucket. Subsamples were poured into two 40-ml and two 4-ℓ glass containers with Teflon lids and a 5-gal polyethylene bucket. The samples were shipped overnight to WES. The 40-ml and 4-ℓ glass containers were stored on ice.

44. Soil sampling. Surface soil samples were collected at the Forest and Magazine 13/14 confined sites for visual classification and DTPA tests. The samples were removed to a depth of approximately 1 ft, placed in plastic

bags, and returned to WES. A surface sample of approximately 3 ℓ was taken from the southwestern portion of the Forest site and the western portion of the Magazine 13/14 site.

Naval Supply Center, Cheatham Annex

45. Sediment sampling. The CAX sampling stations were selected to represent the entire supply pier area. A Ponar sediment sampler was used to remove sediment samples from six locations (CA-1 to 6) adjacent to the supply pier on two separate occasions. Approximately 9 ℓ of sediment was collected on 28 November 1989 for use in physical and chemical analysis. Approximately 25 gal of sediment was collected on 10 April 1990 for use in biological and settling column tests. While sampling on 10 April 1990, CA-4 was relocated just northwest of the November 28 position, CA-5 was relocated just southeast of the November 28 position, and CA-6 was relocated just east of the November 28 position because of objects blocking the positioning equipment's signal. Sample locations are shown in Figure 7.

46. Sample locations CA-3 and CA-5 were originally located closer to the supply pier. However, dredging on the south side of the supply pier in November 1989 removed the shoal material from this location. The width of the prospective dredging area was smaller than normal. Therefore, the sample locations were moved just outside the prospective dredging area and were considered to be representative of shoal material adjacent to the supply pier. Sampling procedures at this site were similar to those followed at NWS Yorktown.

47. Water sampling. Approximately 10 ℓ of surface water for chemical analysis and 5 gal of surface water for elutriate tests were collected adjacent to the supply pier on 01 February 1990 using techniques similar to those used at NWS Yorktown.

Naval Amphibious Base, Little Creek

48. Sediment sampling. NAVPHIBASE LCREEK sampling stations were selected to cover the entire length of the NAVPHIBASE LCREEK Channel and each of the tributaries. A Ponar or Shipek sediment sampler was used to remove sediment samples from 15 locations (LC-1 to 15) in Little Creek Inlet and NAVPHIBASE LCREEK Channel north of the jetties on two separate occasions. Approximately 23 ℓ of sediment was collected on 14 November 1989 and 31 January 1990 for use in physical and chemical analysis. Approximately 25 gal of sediment was collected on 5, 6, and 9 April 1990 for use in biological (10-gal) and settling column (15-gal) tests. Sample locations are shown in

Figures 8 and 9. Sampling procedures at this site were similar to those followed at NWS Yorktown and CAX.

49. Water sampling. Approximately 10 ℓ of surface water for chemical analysis and 5 gal of surface water for elutriate tests were collected in the NAVPHIBASE LCREEK Channel, due east of Piers 12 and 13 on 31 January 1990. The sample was obtained by pumping water from a depth of approximately 35 ft through a non-contaminating pump into two 40-ml and two 4-ℓ glass containers, and a 5-gal polyethylene bucket. Samples were shipped overnight to WES. The 40-ml and 4-ℓ glass containers were stored on ice.

Soil sampling

50. Surface soil samples were collected at the Pier 60/New Magazine, Beach Drive, and Landfill sites for visual classification and to perform testing. A surface sample of approximately 3 ℓ was taken from the southwestern portion of the Pier 60/New Magazine site and the southeastern portion of the Beach Drive site. However, two surface samples of approximately 1.5 ℓ were taken from the southwest portion of the Landfill site and composited. Sampling procedures were similar to those followed at NWS Yorktown.

Thimble Shoal

51. Sediment sampling. Approximately 2 ℓ of sediment was collected from the center of the Thimble Shoal disposal site (TS-1) on 02 February 1990 for physical and chemical analysis. A Ponar sampler was used to obtain the sample with procedures similar to those used at the prospective dredging areas. The location of this sample is shown in Figure 1.

52. Water sampling. Approximately 10 ℓ of water was collected at station TS-1 on 02 February 1990 for chemical analysis. The sample was taken at a depth of approximately 22 ft, using a non-contaminating pump and procedures similar to those used at the prospective dredging areas.

Naval Channel

53. Sediment sampling. Approximately 2 ℓ of sediment was collected from the center of the Naval Channel disposal site (NC-1) on 02 February 1990 for physical and chemical analysis. A Ponar sampler was used to obtain the sample with procedures similar to those used at the prospective dredging areas. The approximate location of this sample is provided in Figure 1.

54. Water sampling. Approximately 10 ℓ of water was collected at NC-1 on 02 February 1990 for chemical analysis. The sample was taken at a depth of approximately 33 ft, using a non-contaminating pump and procedures similar to those used at the prospective dredging areas.

York River

55. Sediment sampling. Approximately 2 ℓ of sediment was collected from the center of the York River disposal site (YR-1) on 02 February 1990 for physical and chemical analysis. A Ponar sampler was used to obtain the sample, and procedures were similar to those used at the prospective dredging areas. The approximate location of this sample is provided in Figure 1.

56. Water sampling. Approximately 10 ℓ of water was collected from YR-1 on 02 February 1990 for chemical analysis. The sample was taken at a depth of approximately 33 ft, using a non-contaminating pump with procedures similar to those used at the prospective dredging areas.

Chesapeake Bay reference site

57. Sediment sampling. Approximately 10 gal of sediment was collected on 12 April 1990 from three locations (CB-1 to 3) in the Chesapeake Bay reference site for biological tests. A Shipek sampler and procedures similar to those used at the prospective dredging areas were used to collect the samples. The approximate location of the samples is provided in Figure 1.

Atlantic Ocean reference site

58. Sediment sampling. Approximately 10 gal of sediment was collected from three locations (AR-1A to 3A) in the Atlantic Ocean reference site on 19 April 1990 for biological tests. Divers were used to obtain the samples because of difficulty experienced with sampling the uniformly graded sand at this site with the Ponar and Shipek samplers. The approximate location of this sample is provided in Figure 1.

Sediment Physical Characteristics

59. The WES Geotechnical Laboratory performed grain-size analysis (sieve and hydrometer), Atterberg Limits, organic content, and water content tests on the sediment from NWS Yorktown, CAX, and NAVPHIBASE LCREEK and the Thimble Shoal, Naval Channel, and York River open-water disposal sites. The grain-size distribution data and Atterberg Limits were used to determine the Unified Soil Classification System (USCS) classification of the sediment collected. Many of the samples collected contained aquatic vegetation, roots, worms, shell fragments, and small pieces of debris. Table 2 provides a summary of the physical analysis of the sediment.

Naval Weapons Station, Yorktown

60. All sediment sampled at NWS Yorktown (NWS-10 to 16) had a USCS classification of CH (highly plastic, inorganic clay). The average liquid limit, plastic limit, and plasticity index of the sediment was 113, 35, and 78 percent, respectively. The plasticity chart for NWS Yorktown, CAX, and NAVPHIBASE LCREEK is provided in Figure 10. The average in situ water content of the sediment was 199.3 percent, the average organic content of the sediment was 7.2 percent, and the average percent passing the No. 200 sieve was 95 percent. The approximate grain-size distribution ranges for the three prospective dredging areas are provided in Figure 11.

Naval Supply Center, Cheatham Annex

61. All sediment sampled at CAX (CA-1 to 6) had a USCS classification of CH (highly plastic, inorganic clay). The sample collected at CA-6 during the 10 April sampling effort contained significantly more shells than the 28 November sample. The average liquid limit, plastic limit, and plasticity index of the sediment was 116, 37, and 79 percent, respectively (see Figure 10). The average in situ water content of the sediment was 190.9 percent, the average organic content of the sediment was 7.2 percent, and the average percent passing the No. 200 sieve was 97 percent (see Figure 11).

Naval Amphibious Base, Little Creek

62. Tributaries. Of the seven tributary samples, five (LC-1,2,3,8, and 9) at NAVPHIBASE LCREEK had a USCS classification of CH (highly plastic, inorganic clay) and the other two samples had a classification of SC (clayey sand). The average liquid limit, plastic limit, and plasticity index of the sediment from the tributaries was 69, 25, and 44 percent, respectively (see Figure 10). The average in situ water content of the sediment was 142.7 percent, the average organic content of the sediment was 4.9 percent, and the average percent passing the No. 200 sieve was 70 percent (see Figure 11).

63. Channel. Of the eight channel samples at NAVPHIBASE LCREEK (LC-4,7, and 10 to 15), five had a USCS classification of SM (silty sand), the remaining three channel samples had USCS classifications of SM-SC (silty or clayey sand), SP-SM (poorly graded sand or silty sand), and SC (clayey sand). Note that all channel sediment sampled was primarily sand. Two of the samples collected exhibited non-plastic behavior. One of the three samples collected at LC-12 during the April sampling effort contained a significantly greater fraction of fines than the other two. The average liquid limit, plastic limit, and plasticity index of the two samples were 28, 17, and 12 percent,

respectively (see Figure 10). The average in situ water content of the sediment was 34.0 percent, the average organic content of the sediment was 1.4 percent, and the average percent passing the No. 200 sieve was 26 percent (see Figure 11).

Thimble Shoal

64. The sediment sampled at the Thimble Shoal disposal site (TS-1) had a USCS classification of SP (poorly graded sand or gravelly sand with little or no fines) and therefore exhibited non-plastic behavior. The in situ water content of the sediment was 24.5 percent, the organic content of the sediment was 1.8 percent, and the percent passing the No. 200 sieve was 2 percent.

Naval Channel

65. The sediment sampled at the Naval Channel disposal site (NC-1) had a USCS classification of SM (silty sand) and therefore exhibited non-plastic behavior. The in situ water content of the sediment was 29.0 percent, the organic content of the sediment was 0.9 percent, and the percent passing the No. 200 sieve was 14 percent.

York River

66. The sediment sampled at the York River disposal site (YR-1) had a USCS classification of CH (highly plastic, inorganic clay) and therefore exhibited non-plastic behavior. The liquid limit, plastic limit, and plasticity index of the sediment were 94, 31, and 63 percent, respectively. The in situ water content of the sediment was 148.6 percent, the organic content of the sediment was 5.1 percent, and the percent passing the No. 200 sieve was 96 percent.

Sediment Chemical Characterization

67. A sediment chemical inventory was performed on samples taken from the prospective dredging areas. The purpose of the inventory was to obtain information on the chemical constituents present to guide decisions on the need for further environmental testing.

68. Previous sediment analyses described in the Phase I study had indicated the presence of metals, pesticides, polynuclear aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs), although at relatively low concentrations. At previous coordination meetings, the resource agencies had not identified any additional contaminants of concern. Based on this, the samples

were analyzed for the full EPA priority pollutant list (139 constituents total), but were not analyzed for any additional constituents.

69. Results of the inventory are shown in Table 3. Most of the organic constituents on the EPA priority pollutant list were not detected in any of the samples. Table 3 therefore shows only those parameters for which the concentration at one or more stations was above the detection limit.

70. Moderate concentrations of metals (including cadmium and mercury) were detected in the samples for all three prospective dredging areas. Some of the PAHs, pesticides, and PCBs were detected at some stations, but concentrations were low. Methylene chloride was detected in practically every sample; however, this solvent is not of concern since it is used in laboratory cleanup and analytical procedures and was also detected in quality analysis/ quality control (QA/QC) blanks.

Need for Additional Testing

71. The results of the sediment chemical characterization served as the basis for an evaluation of the need for additional environmental testing. The historical data documented in the Phase I report indicated a "reason to believe" that contaminants were present in the sediments at concentrations which would warrant more detailed consideration. The sediment chemical characterization from the Phase II samples confirmed that the sediments throughout the NWS Yorktown, CAX, and NAVPHIBASE LCREEK tributaries contained metals (including cadmium and mercury) and low concentrations of some organic constituents. However, the levels of sediment contamination evident in the Phase II samples were generally lower than those in the historical record. This could possibly be due to a gradual reduction in contamination because of improved source control, or possibly from better analytical techniques now available.

72. For open-water disposal options, the technical guidance for determining acceptability of material for open-water disposal (US Environmental Protection Agency/US Army Corps of Engineers 1990) contains a tiered approach to testing. In Tier I, all available data, to include a sediment chemical inventory, are examined to determine if water column and benthic environmental testing and evaluations are required. Since ocean disposal sites are under consideration for this LTMS, the presence of cadmium and mercury in the sediments mandated that such testing be conducted to evaluate ocean options. A

testing and evaluation program for open-water disposal options was therefore performed for this Phase II effort as described in Part IV.

73. As described in the Phase I report, the use of CDFs would be considered to be the most logical alternative for disposal of materials found to be unsuitable for open-water disposal. There is not a structured tiered testing approach for evaluation of CDF options. However, the presence of metals in the sediments indicated the need for limited environmental testing and assessments for the CDF alternatives as described in the Corps Management Strategy (Francingues et al. 1985). A testing and evaluation program for the CDF options was therefore performed as described in Part V.

Sample Compositing Scheme

74. Samples from individual stations were composited for additional engineering and environmental testing, based on the results of the physical and chemical characterization. All station samples for both NWS Yorktown and CAX were similar; therefore, a single composite for NWS Yorktown (stations NWS-10 to 16) and a single composite for CAX (stations CA-1 to 6) were developed. There was a distinct difference between the character of the NAVPHIBASE LCREEK Tributary and Channel samples. Also, the entrance channel has been historically dredged as a separate item from any required dredging in the tributaries. Therefore, separate composites for the NAVPHIBASE LCREEK tributaries (1,2,3,5,6,8, and 9) and Channel (LC-4,7, and 10 to 15) were developed. This yielded a total of four composite samples for most additional testing.

75. The engineering tests for CDF evaluations were composited differently. For these tests, the behavior of the fine-grained sediments governs the design of the CDF. Also, since no potential CDF sites were located on CAX property, the material from CAX was assumed to be placed in the same CDF as that for NWS Yorktown. Based on these considerations, two separate composites were developed for engineering tests for CDF evaluations. These were an NWS Yorktown/CAX composite (stations NWS-10 to 16 and CA-1 to 6) and a NAVPHIBASE LCREEK tributaries composite (stations LC-1,2,3,5,6,8,and 9).

Intended Use of Test Results

76. The samples taken for physical and chemical characterization in this Phase II study were collected from stations distributed throughout the

areas historically dredged at each of the three facilities. Composites of these samples used for conducting additional environmental testing therefore reflect the overall character of the sediments from the study area. Test results using the composite samples are intended for "rangefinding" evaluations; i.e., to determine the overall suitability of material from the given project area for a given disposal alternative. This approach is appropriate for an LTMS evaluation aimed at identifying practicable long-term disposal solutions.

77. Sampling plans, compositing schemes, and testing plans for this Phase II study were not developed for a specific area or volume of sediment to be dredged. The test results in this Phase II report are therefore NOT intended to be used to support a specific permit application. When specific areas to be dredged are identified in the future, sampling and testing for that specific permit application may be necessary. However, it is hoped that the results from the "rangefinding" tests in this study would serve not only to identify suitable long-term disposal alternatives, but also to provide an initial screening or "reason to believe" evaluation for some projects. This should also reduce the cost and complexity of any testing and assessments required for future specific permit applications.

PART IV: ASSESSMENT OF OPEN-WATER DISPOSAL OPTIONS

General

78. Open-water disposal options were assessed using available data on site characteristics and the results from laboratory tests and modeling. The open-water disposal sites evaluated consisted of five in-bay and two ocean sites. Placement of materials from the four prospective dredging areas was considered for each of the seven sites, which resulted in 28 possible options for open-water placement.

79. The assessment of open-water disposal options consisted of the following:

a. Development of generalized site hydrodynamic conditions based on existing data.

b. Standard elutriate testing to determine potential contaminant release to the water column during open-water disposal.

c. Benthic bioassay and bioaccumulation tests to determine potential contaminant effects on the benthos.

d. Open-water disposal modeling to predict the short-term fate of material placed at the sites, to include initial water column mixing, and descent and accumulation of material on the bottom.

e. Mound erosion and transport modeling to predict the long-term fate of the mounds; i.e., whether the sites were predominantly accumulative or dispersive.

Considerations for Open-Water Disposal

Dredging method

80. Placement of materials from all the prospective dredging areas to any of the open-water sites involves long haul distances. Although dredging contractors normally have the option of using equipment of their choice, for long haul distances, mechanical dredging and transport by barge are the most efficient options. Because of this, it was assumed that mechanical dredging and filling of bottom-dump barges would be the dredging technique for all open-water disposal options.

Behavior of barge discharges in open water

81. Bucket dredges remove sediment at nearly its in situ density and place it in barges or scows for transportation to the disposal area. Although several barges may be used so that the dredging is essentially continuous,

disposal occurs as a series of discrete discharges. The dredged material may be a slurry similar to that in a hopper dredge, but often sediments dredged by clamshell remain in fairly large consolidated clumps and reach the bottom in this form. Whatever its form, the dredged material descends rapidly through the water column to the bottom, and only a small amount of material remains suspended (US Army Corps of Engineers 1983).

Short-term behavior of material placed in open water

82. The short-term behavior of material placed in an open-water disposal site is defined as that behavior which occurs within the first few hours of discharge. Several distinct phases have been observed. First, the convective descent phase, during which the dump cloud or discharge jet falls under the influence of gravity. Second, the dynamic collapse phase, occurring when the descending cloud or jet impacts the bottom. And finally, the passive transport-dispersion, commencing when the material transport and spreading are determined more by ambient currents and turbulence than by the dynamics of the disposal operation.

83. Each barge-load of material released behaves in a similar fashion. Therefore, the concentrations of suspended sediment and any associated contaminants in the water column as a function of time and location, and the area of deposition of material from a single barge-load on the bottom, are governed by the short-term behavior. Unless the current velocities are unusually high, the vast majority of the material released from barges will settle to the bottom close to the point of discharge.

Long-term behavior of dredged material mounds

84. For most dredging projects, multiple barge-loads of material will be placed at an open-water site. As material from successive barge-loads is deposited on the bottom, a mound of dredged material is formed. Once the project is completed, the resulting dredged material mound is exposed to the long-term processes of consolidation and erosion. Consolidation of the material will tend to reduce the size of the mound and increase the shear strength of the material comprising the mound. Erosion can cause material to be transported from the mound or can cause the centroid of the mound to migrate in the direction of the predominating currents. The potential for erosion is a function of the bottom currents and wave conditions at the site, and must account for both normal conditions and those due to periodic storm events.

Potential Open-Water Disposal Sites

General

85. Considering the difficulty in locating a new open-water disposal site and the relatively small volumes of material dredged from the NWS Yorktown, CAX, and NAVPHIBASE LCREEK, only historically used open-water disposal sites, located within a reasonable haul distance, were considered as potential disposal sites in the Phase I study. These potential open-water disposal sites include (a) Dam Neck, (b) Norfolk, (c) Thimble Shoal, (d) Naval Channel, (e) Wolf Trap Alternate, (f) York River, and (g) Rappahannock Shoal Alternate. Two of these sites (Dam Neck and Norfolk) are located in the open Atlantic Ocean, while the remaining five sites are located inside lower Chesapeake Bay. The Wolf Trap and Rappahannock Shoal disposal sites are located adjacent to respective alternate sites. As mentioned in the Phase I report, the alternate sites were determined to be more suitable. Therefore, the Wolf Trap and Rappahannock Shoal sites were not considered in the Phase II investigation. The locations of all the sites are shown in Figure 1.

86. Additional information on site hydrodynamics and characteristics was gathered during Phase II for use in evaluation of open-water disposal alternatives. A description of each site and site characteristics are given in the following paragraphs, and a summary of the general characteristics is presented in Table 4.

Dam Neck

87. The Dam Neck site is an ocean site located approximately 3 nautical miles southeast of Virginia Beach, VA and 7 nautical miles south of the Chesapeake Bay mouth. The site is located on the nearshore continental shelf and is surrounded by productive marine waters. In addition, the site is located within a US Navy firing range. On March 31, 1988, the Dam Neck site was designated by the EPA as an approved open-water disposal site. The site has an area of 10 square miles and an average water depth of approximately 40 ft mlw. In 1985, the site was expanded to a length of 30,000 ft and a width that tapers from 13,000 to 6,000 ft.

88. The Dam Neck site was first used in 1967 for the construction of the Thimble Shoal Channel and has since been used for new work and maintenance dredging from the Thimble Shoal, Cape Henry, and Atlantic Ocean Channels. Between 1967 and 1985, about 20.4 million cu yd of dredged material was deposited at the site. The material deposited ranged in size from silt to

coarse sand. Monitoring has indicated that no significant environmental effects can be attributed to previous disposal of dredged material at this site.

89. The current capacity of this site is approximately 65 million cu yd, with fill to the 35-ft contour. The site has an expected useful life of 50 more years if only material dredged from the Thimble Shoal, Cape Henry, and Atlantic Ocean Channels is disposed there. However, the site only has an expected life of 10 more years if the material dredged from the three channels and the Norfolk Harbor Project is disposed there.

90. A site management plan based on the use of seven sub-areas was placed in action after the site was expanded. The purpose of the plan is to provide for the uniform distribution of material and the segregation of material by general type (sands and fine-grained material) within the site (US Army Engineer District, Norfolk 1989).

91. Currents measured in the vicinity of the disposal site average between 5 cm/sec and 9 cm/sec during the summer, and between 4 cm/sec and 6 cm/sec during the fall. Near-bottom currents average between 0 cm/sec and 2 cm/sec during the summer and between 1 cm/sec and 3 cm/sec during the fall. Detailed current measurements have been obtained from stations located in the Dam Neck disposal site. Bottom currents were oriented north-south at 3 cm/sec to 12 cm/sec during the presence of moderate wave action (US Army Engineer District, Norfolk 1985a and 1985b). Considering the largest of the recorded current values of 12 cm/sec, it appears the typical non-storm velocities at the Dam Neck site are on the order of 0.4 ft/sec. A plan of the site showing site characteristics is shown in Figure 12.

<u>Norfolk</u>

92. The Norfolk site is located approximately 17 nautical miles east of the mouth of the Chesapeake Bay. This site is circular in shape and covers an area of approximately 65 square miles (radius = 24,000 ft) with an average water depth of 70 ft. This site is being studied by the EPA for Section 102 designation (i.e. designation for general use). However, the designation process could be lengthy, and the site should therefore be considered as a long-term alternative under the 50-year LTMS. Assuming a fill elevation of 50 ft, this site had a capacity of approximately 1.34 billion cu yd.

93. Boicourt (1981) obtained current measurements at four moorings on the cross-shelf off of Chesapeake Bay. Velocities in a water depth of 18 m were found to be 32 cm/sec during the summer. Winter currents were in excess

of about 40 cm/sec. Nearly all occasions of high velocity were during times when directions were south-southwest, parallel to the isobaths. Boicourt concluded that sediment transport events are therefore likely only during strong northerly winds, and their transport direction is to the south. Summer current velocities never reached 35 cm/sec during this measurement period.

94. Darby et al. (1981) monitored the first 3 of 20 test disposals at the site, and found that disposed material was largely confined to within a 300-m radius from a point source. Surface winds during this time resulted in water currents up to 62 cm/sec (2.0 ft/sec). A plan of the site showing site characteristics is shown in Figure 13.

Chesapeake Bay sites

95. Five sites in lower Chesapeake Bay are under consideration. The Chesapeake Bay is an unusually long and shallow estuary oriented on a north-south axis, and extends approximately 190 miles north from its mouth. The bay has an average depth of around 28 ft, with a maximum width of about 30 miles. Tides in the bay are predominantly semidiurnal and are characterized by low amplitudes (under 2 ft at most locations).

96. The US Army Engineer District, Baltimore has performed extensive investigations on the active Wolf Trap Alternate and Rappahannock Shoal Alternate sites. However, the remaining bay sites have not been used since the advent of the National Environmental Protection Act (NEPA) and other environmental laws. Consequently, there is little data available for these sites.

97. Additional information on the hydrodynamics of the in-bay sites was developed using results from the Chesapeake Bay physical model (Scheffner et al. 1981). The Chesapeake Bay model, a fixed-bed model constructed to a horizontal scale ratio of 1:1000 and a vertical scale ratio of 1:100, reproduced the Chesapeake Bay from the ocean to the head of tides for each tributary. The model was equipped with the necessary appurtenances to accurately reproduce and measure tidal heights, tidal currents, salinity distributions, and freshwater inflows. Tidal heights and tidal velocities were calibrated and verified using the M_2 constituent tide. This component accounted for about 92 percent of the total tidal energy of the system.

98. Velocity sections were established at appropriate locations throughout the Bay model, and specific velocity stations were positioned along each section. Velocity stations were located at equal intervals along the sections. An estimate of the current magnitudes at the Chesapeake Bay

open-water disposal sites can be obtained from the velocity-time histories at the stations along the various sections in the near vicinity of the sites.

Thimble Shoal site

99. The Thimble Shoal site is located in the Chesapeake Bay approximately 7 miles north of the entrance to Little Creek Inlet or just northwest of the intersection of the Chesapeake Bay Bridge Tunnel and Thimble Shoal Channel. The area of this site is approximately 1 square mile. In 1965, this site was used for the disposal of material dredged from Piers 1-9 at NAVPHIBASE LCREEK. Water depth in this location is about 22 ft. The Thimble Shoal site is located off the mouth of the James River, where maximum non-storm velocities are about 2.0 ft/sec. At the nearest velocity section on the ocean side of Thimble Shoal, the maximum velocities are about 2.2 ft/sec. Hence, for the Thimble Shoal site, it appears the average maximum non-storm velocities are around 2.1 ft/sec. A plan of the site showing site characteristics is shown in Figure 14.

Naval Channel site

100. The Naval Channel site is located in the Chesapeake Bay on the southeast end of the York River Entrance Channel. This site has an area of 1,056 acres and its bottom is relatively flat with water depths ranging from 32 to 37 ft mlw. This site was used in 1951-52 during the construction of the York River Channel.

101. The nearest velocity section on the ocean side of Thimble Shoal is also appropriate for ascertaining velocities at the Naval Channel site. Here the maximum velocities were found to be about 2.2 ft/sec. The nearest velocity section on the up-bay side of the disposal site indicates current magnitudes of about 1.2 ft/sec. Hence, it appears the average maximum non-storm velocities at the Naval Channel site are about 1.7 ft/sec. The water at the Naval Channel site is significantly deeper than at the Thimble Shoal site, resulting in lower average current velocities. A plan of the site showing site characteristics is shown in Figure 15.

York River site

102. The York River site is located in the York River just upstream of Sandy and Tue Points and the York River mouth. The approximate center of this site is located 300 yd southeast of Nun Buoy 24. In 1965, material dredged from CAX and NWS Yorktown was disposed at this site. The water depth at the York River site is about 50 ft.

103. A Chesapeake Bay model velocity section was established directly across the York River site. Here the average maximum non-storm velocity was found to be about 1.4 ft/sec. A plan of the site showing site characteristics is shown in Figure 16.

Wolf Trap Alternate site

104. The Wolf Trap Alternate site is located in the Chesapeake Bay southwest of the Wolf Trap site and slightly overlapping it. The dimensions of this site are approximately 2 by 4 nautical miles with an average water depth of 38 ft and a flat bottom contour. As of July 1986, this site had a capacity of approximately 64.7 million cu yd, with fill to the 30-ft contour. This site was subsequently used for the disposal of 20.7 million cu yd of material dredged from the York Spit Channel as part of the Baltimore Harbor and Channels Deepening Project and is the anticipated site for future maintenance material from this project.

105. The nearest velocity section on the up-bay side of the Naval Channel site is appropriate as the nearest velocity section on the down-bay side of the Wolf Trap Alternate site. Here, the maximum non-storm average current velocity was found to be 1.2 ft/sec. At the nearest velocity section on the up-bay side of the Wolf Trap Alternate site, the maximum non-storm currents are about 1.8 ft/sec. Hence, the average maximum current velocity at the Wolf Trap Alternate site is about 1.5 ft/sec. A plan of the site showing site characteristics is shown in Figure 17.

Rappahannock Shoal Alternate Site

106. The Rappahannock Shoal Alternate site is located in the Chesapeake Bay at approximately 2 nautical miles south of the Rappahannock Shoal site and measures approximately 1 by 5 nautical miles with an average water depth of 40 ft. This site is slightly sloping from east to west and relatively flat from north to south. As of 1986, this site had a capacity of approximately 56.6 million cu yd, with fill to the 30-ft contour. This site was used for the disposal of 8.2 million cu yd of material dredged from the Rappahannock Shoal Channel as part of the Baltimore Harbor and Channels Deepening Project and is the anticipated site for future maintenance material from the project. Here, the water depth is about 40 ft.

107. The nearest velocity section up-bay from the Wolf Trap Alternate site is appropriate as the nearest velocity section down-bay from the Rappahannock Shoal Alternate site, where the maximum non-storm velocities are about 1.8 ft/sec. The non-storm velocities at the nearest velocity section up-bay

from The Rappahannock Shoal Alternate site also are about 1.8 ft/sec. Hence, the average maximum non-storm velocities at the disposal site are about 1.8 ft/sec. A plan of the site showing site characteristics is shown in Figure 18.

Reference Sites

108. The testing procedures for evaluation of open-water disposal call for testing of a reference sediment, providing a point of reference to which effects of dredged material disposal as defined by the testing can be compared. The definition of a reference sediment is as follows (US Environmental Protection Agency/US Army Corps of Engineers 1990):

> A reference sediment is a sediment, substantially free of contaminants, that is as similar to the grain size of the dredged material and the sediment at the disposal site as practical, and reflects conditions that would exist in the vicinity of the disposal site if no dredged material disposal had ever occurred, but all other influences on sediment condition had taken place. These conditions have to be met to the maximum extent possible...The reference sediment serves as a point of comparison to identify potential effects of contaminants in the dredged material.

109. The procedures allow for collection and testing of a reference sample from a single sampling point each time a dredged material is evaluated for suitability (reference point approach) or collection of reference samples from an area for one-time testing (reference area approach). Since the testing procedures have recently been developed, no decisions have yet been made on which approach will be used for the bay and ocean sites under consideration.

110. For purposes of this LTMS, two separate reference areas were selected which met the conditions described above. One site was located in the Chesapeake Bay and the other was located in the Atlantic Ocean. The selected reference locations are geographically adjacent to the sites and were expected to be substantially free of contaminants and representative of conditions adjacent to the site but not directly influenced by previous disposal. It was not practical to base the selection of the reference sites on bottom sediment grain size similar to the dredged material and the sediment at the disposal sites since these sediment grain sizes were markedly different. If open-water disposal sites are selected for disposal, a different reference site may be more appropriate.

111. The Atlantic Ocean reference site is located just southeast of Smith Island Shoal (see Figure 1). This site was selected based on existing bottom sediment characteristics and prevailing current directions in the vicinity of the Dam Neck and Norfolk disposal sites. Since both the Dam Neck and Norfolk sites are being considered, it was deemed cost-effective to use one reference for these sites.

112. The Chesapeake Bay reference site is located between the York River Entrance and York Spit channels (see Figure 1). This site was selected based on its centralized location with respect to all Chesapeake Bay sites under consideration. Similarly, since the bay sites are located within the same general area, one reference area was deemed cost-effective. It was not practical to base the selection of the bay reference areas on bottom sediment grain size similar to the dredged material and the sediment at the disposal sites since these sediment grain sizes were markedly different (see descriptions in Part III).

113. Note that the testing for the LTMS is for purposes of "rangefinding." If open-water disposal alternatives and sites are later selected, a different reference site or reference area may be more appropriate.

Tiered Testing Approach

114. A major requirement for the assessment of open-water options was the determination of suitability of the materials for open-water disposal. This determination involved laboratory tests for evaluating potential water column and benthic effects due to the presence of contaminants. This testing was conducted using the approaches given in the latest draft revision of the Section 103 implementation manual (US Environmental Protection Agency/US Army Corps of Engineers 1990). These procedures call for a tiered testing approach with the tiers generally following this sequence:

- a. Tier I evaluation; i.e., a "reason to believe" determination if contaminants are present and could potentially present an environmental problem,
- b. Tier II tests involving chemically based tests and assessments.
- c. Tier III tests involving biological testing.

115. In general, the successive tiers involve more complex and costly evaluations. However, the tiered testing approach calls for conducting only those tests deemed necessary with decisions made in the initial tiers if

possible. The Phase I assessment of past information (Zappi, Palermo, and LaSalle 1990) and the sediment chemical analysis conducted for Phase II, as described in Part III, indicated that contaminants were present. Further, the presence of cadmium and mercury in the sediments mandated benthic bioassay and bioaccumulation testing for assessment of ocean disposal options. Therefore, Tier II and Tier III testing were conducted for this Phase II evaluation.

Standard Elutriate Testing

116. Standard elutriate tests (US Environmental Protection Agency/ US Army Corps of Engineers 1990) were conducted on the four composite samples from the prospective dredging areas. The standard elutriate test is a Tier II test designed to simulate the release of contaminants to the dissolved phase during open-water disposal. For this study, the contaminant concentrations resulting from the test were compared to Federal marine acute criteria.

117. The standard elutriate test consists of mixing sediment and water at a 1:4 volumetric ratio, agitating the mixture for 30 min, allowing the mixture to settle for 1 hr, and extracting the sample. The sample is filtered through a 0.45-μm filter prior to chemical analysis.

118. The sediment chemical inventory for samples from the prospective dredging areas was examined to determine the appropriate chemical analysis for the elutriates. Metals were detected in samples from all of the prospective dredging areas. Pesticides and PCBs were also detected in some sediment samples. However, the concentrations were low, and these contaminants are tightly bound to sediment particles. PAHs were also detected in some samples and are not as tightly bound as pesticides and PCBs. The elutriate samples were therefore analyzed for metals and PAHs only.

119. Results of the standard elutriate tests are shown in Table 5. Only those parameters that were detected in the elutriates are tabulated. None of the PAHs were detected in the elutriates. Metals were detected, but all were at concentrations below the Federal acute marine water quality criteria.

Benthic Bioassay Testing

General

120. There are no Tier II benthic toxicity test procedures. Therefore, Tier III benthic bioassay tests were performed. The purpose of benthic sediment bioassays is to assess the potential toxicity of dredged material in order to provide an objective, technically sound basis for determining disposal options. To conduct such tests, the toxicities of the project materials are compared to those of reference sediments representing the disposal site environs. In this test, potential impacts of dredged material from Naval installations adjacent to the Chesapeake Bay are compared to two reference sites: in-bay and ocean.

Approach

121. Sediments. Sediments were collected from four different sites in southern Chesapeake Bay: two sites adjacent to Naval Amphibious Base, Little Creek; one site in the York River adjacent to the NWS Yorktown; and a site near CAX. In addition, two reference sediments were collected: a site within the Chesapeake Bay, and an Atlantic Ocean reference site.

122. All sediments were received at WES in 5-gal sealed buckets, packed in ice for transport. Each project sediment was then homogenized, pre-sieved through 1-mm stainless steel mesh, and stored in 1-gal sealed buckets. Particle size analysis and organic carbon from loss on ignition (LOI) were calculated for each of the test sediments. The particle size was calculated according to the methods of Patrick (1958). Loss on ignition was determined using the procedure of Allen et al. (1974). Sediments were stored at 4° C for no more than 2 weeks prior to testing.

123. Test organism. The benthic infaunal polychaete worm, *Neanthes arenaceodentata*, was used to evaluate the acute lethality of sediments from Naval facilities in southern Chesapeake Bay. This marine worm has a cosmopolitan geographic distribution from the English Channel to Spain, Massachusetts to Florida, Southern California to Mexico, localities in the Pacific, India, and Africa (Pettibone 1963). In the Chesapeake Bay area, *N. arenaceodentata* has been found off the Rappahannock River, Hampton Roads, and Tompkin Island (Wass 1972).

124. Unlike many test species, *Neanthes* can be used to evaluate suspended particulate material as well as solid phase sediments. In solid phase

tests, it maintains intimate contact with the sediment, building one to several mucoid tubes in the upper 2-3 cm of sediment. In both test types, it readily ingests sediment while foraging for food and tube-building material.

125. *Neanthes* is particularly well-suited for laboratory evaluations of dredged material because its life cycle has been well established and documented in the literature (US Environmental Protection Agency/US Army Corps of Engineers 1991). Life cycles can be completed in the laboratory so cultures producing test organisms of known age and background on a predictable basis are possible. The WES obtained stock cultures of *N. arenaceodentata* over 2 years ago from Dr. Donald J. Reish, California State University at Long Beach. Continuous laboratory cultures have been maintained at WES using methods outlined by Reish (1980) and Pesch and Schauer (1988).

126. When worms are sexually mature they establish pairs and occupy a common tube. The female deposits her eggs and dies shortly thereafter. The male remains to "incubate" the eggs. Development of larvae occurs entirely within the parental tube. Young worms emerge and begin feeding 3 to 4 weeks after egg deposition. The emergent juveniles (EJs) start pairing about 6 weeks after leaving the tube. Egg mass deposition begins 4 weeks to 6 weeks later to complete the cycle.

127. Cultures are maintained in 30-ℓ aquaria under static-renewal conditions. Every 3 weeks, media is completely renewed with 30-ppt seawater (Instant Ocean®). The temperature is maintained at 20° C and the photoperiod is 18 hr of light. Animals are fed twice weekly a combination of Tetramin® and alfalfa; both finely ground and pre-sieved to < 1 mm. When worms are 10 weeks old, they are sexed, and individual pairs are placed in 600-ml beakers with weekly seawater renewals. Beakers are monitored daily for egg mass deposition and the subsequent appearance of EJs. Three-week-old juveniles are used to initiate sediment bioassays.

Sediment bioassays

128. Sediment bioassays were conducted according to general procedures outlined in the newly revised testing manual for ocean disposal (US Environmental Protection Agency/US Army Corps of Engineers 1991). Stored sediment was allowed to come to room temperature (20° C) and then rehomogenized with a stainless steel spatula. Sediment was added to 600-ml beakers to a depth of 2-3 cm. Seawater was added to all beakers for a total volume (sediment plus overlying water) of 500 ml. Beakers were placed in a water bath (20° C) with an 18-hr photoperiod and provided trickle flow aeration.

129. The following day, juvenile (3 weeks old) *Neanthes* were randomly assigned to each beaker. Previous experiments indicated a maximum of four worms/beaker with sediment and two worms/beaker without sediment could be added without intraspecific density effects on survival and growth. High levels of ammonia (5 mg/ℓ to 15 mg/ℓ of unionized NH_3) have been observed in previous bioassays within 24 hr after the addition of sediment. For that reason, 80 percent of the seawater in each beaker was replaced just prior to adding worms. Initial and final (10-day) water samples were collected from each of the replicates for analysis of unionized NH_3. There was no seawater renewal during the 10-day test. Temperature, salinity, dissolved oxygen, and pH were monitored daily. After 10 days, animals were recovered from each beaker by gentle wet sieving. Missing animals were assumed to be dead. Percent survival in each beaker was recorded.

<u>Data analysis</u>

130. There were seven treatments: four sediments from the prospective dredging locations, two reference sediments (in-bay and ocean reference), and a positive laboratory control (no sediment). Both reference sediments and those obtained from the prospective dredging areas were replicated five times while controls were replicated 10 times. Since controls were run without sediment, only two worms per beaker were used to avoid intraspecific density effects. Control survival was more than 90 percent. The bioassay was therefore considered valid and statistical analysis performed. Recommended analysis consists of tests for normality and homogeneity of variance, followed by simple one-way analysis of variance (ANOVAs) comparing project sediments to each of the reference sediments (US Environmental Protection Agency/US Army Corps of Engineers 1990). However, since 100-percent survival was observed for all five replicates in one of the reference sediments, a measure of sample variance was lacking, which eliminated the use of an ANOVA. Instead, a t-test was used to compare means with no variance (i.e., 100-percent survival in all replicates) to a treatment mean with variance (Sokal and Rohlf 1981).

<u>Results</u>

131. Temperature and salinity were relatively constant for the treatments with means of 22° C and 28 ppt, respectively. Mean pH ranged from 8.28, to 8.82 with higher values observed in project sediments (CAX and Yorktown) and lower values in the reference and control treatments. Mean dissolved oxygen was greater than 5.00 mg/ℓ for all treatments, while NH_3 was less than 1.00 mg/ℓ.

132. Grain size and percent LOI (a measure of organic carbon) were determined for each of the sediments tested. The Atlantic Ocean reference, bay reference, and NAVPHIBASE LCREEK Channel sediments were predominately (more than 80 percent) sand. The NWS Yorktown, CAX, and NAVPHIBASE LCREEK Tributaries samples were higher in clay content (40-70 percent). Percent LOI indicated that the NWS Yorktown, CAX, and NAVPHIBASE LCREEK Tributaries sediments were also higher in organic carbon compared to the other test sediments.

133. Percent survival for the tests is shown in Table 6. Percent survival was high in the controls (100 percent), ocean reference (100 percent), and bay reference (95 percent). Survival was also high in sediments from the four prospective dredging areas: NAVPHIBASE LCREEK Channel (100 percent), NAVPHIBASE LCREEK Tributaries (90 percent), NWS Yorktown (90 percent), and CAX (95 percent). Paired comparisons between survival in each of the sediments from the prospective dredging areas to that in both reference sediments (Table 7) indicated no significant differences at P less than 0.05 (see Table 8).

Summary

134. Bioassays were conducted on four composite sediments for comparison with sediments from two reference sites. This test was performed with the marine polychaete worm *Neanthes arenaceodentata* (US Environmental Protection Agency/US Army Corps of Engineers 1990). Results from this test indicated that there were no significant differences between material from the areas dredged and either of the two reference sites in terms of *Neanthes* survival. On the basis of these results, there appears to be little potential for unacceptable adverse environmental impact as a result of either in-bay or ocean disposal of sediments from any of the four prospective dredging areas.

Benthic Bioaccumulation Testing

135. Tier II and Tier III assessments for benthic bioaccumulation of contaminants were performed as described in the MPRSA testing manual (US Environmental Protection Agency/US Army Corps of Engineers 1990). Bioaccumulation testing was required because ocean sites were under consideration and the sediment chemical inventory indicated that cadmium and mercury were present in the sediments.

Theoretical bioaccumulation potential

136. The assessment procedures allow for a chemically based assessment in Tier II for bioaccumulation of neutral organic contaminants such as PAHs,

PCBs, pesticides, and phthalates. This assessment is the theoretical bioaccumulation potential (TBP) calculation. TBP is a calculation that normalizes the concentration of neutral organic contaminants in sediments by the sediment total organic carbon (TOC) and predicts the potential bioaccumulation of the contaminants in an organism of interest normalized by the organism's lipid concentration. Using sediment chemical inventory data, the TBP was calculated for 18 neutral organics in organisms that were 1-, 2-, and 6-percent lipid. Results are shown in Tables 9 and 10.

137. The TBP results indicate that none of the pesticides or PCBs analyzed are of concern in the given sediments. However, the NAVPHIBASE LCREEK Tributary composite showed relatively high potential for bioaccumulation of PAHs, indicating that further bioaccumulation evaluation for PAHs would be required in Tier II for that composite.

138. There is no equivalent Tier II chemically based assessment for bioaccumulation for metals. However, comparison of metals concentrations in sediments from the prospective dredging areas and reference sediments indicated that Cd, Cr, Cu, Hg, Ni, Pb, and Zn concentrations in the sediments from the prospective dredging areas exceeded the concentrations in the two reference sediments. Therefore, bioaccumulation potential for metals was evaluated using Tier III bioaccumulation tests.

Bioaccumulation testing

139. Procedures. Tier III bioaccumulation testing was performed on all sediment composites and on Bay and Ocean reference samples. The experimental protocol was that described in US Environmental Protection Agency/US Army Corps of Engineers (1990). Each sediment was aliquoted to 2.5-ℓ glass crystallizing dishes. Several dishes containing the same sediment were placed into a 75-ℓ aquarium with flowing artificial seawater.

140. The aquaria used in these tests are part of the Flow-through Aquatic Toxicology Exposure System (FATES), shown schematically in Figure 19. FATES can simulate environmentally realistic conditions typical of the disposal sites. The system was developed at the University of California Bodega Marine Laboratory in the 1970s and has since been used in numerous investigations involving bioavailability and bioaccumulation from natural sediments. Seawater in the aquaria was maintained at 35 ppt salinity and 14° C. The flow-through seawater system replaced two aquarium volumes per 24-hr period. Temperature, salinity, pH, and dissolved oxygen levels were monitored in each aquarium at 6-hr intervals throughout the 28 days of exposure.

141. After the water had been allowed to clear and equilibrate with the bedded sediment in the crystallizing dishes, bivalve molluscs (*Macoma nasuta*) were placed in the dishes. This species was chosen as the test organism in accordance with the MPRSA testing manual guidance (US Environmental Protection Agency/US Army Corps of Engineers 1990), and also because the contaminants of interest included both metals and PAHs. *Macoma* is a deposit-feeding clam that lives in close association with the test sediments and has little or no capability to metabolize PAHs. The organisms were supplied by a reputable dealer, shipped to WES, and held without feeding for a period of one week prior to their use in the tests.

142. After 10 days of exposure to the sediments, six replicate samples of clams from each test and reference site were removed, and archived for subsequent trace metal analysis. The clams were allowed to depurate overnight without contact with the test sediments. After 28 days of exposure to the sediments, the remaining clams were removed, allowed to depurate overnight, and archived for analysis of PAHs.

143. Results. Analysis of the test sediments and comparisons with the two reference sediments indicated that Cd, Cr, Cu, Pb, Hg, Ni, and Zn levels in the test sediments exceeded the levels for those same metals in the two reference sediments. Bioaccumulation for these metals was therefore determined. Results are shown in Tables 11 and 12. In most cases the organisms exposed to test sediments bioaccumulated less than organisms exposed to either of the reference sediments. No sediment caused greater bioaccumulation of all analytes than that measured in the organisms exposed to reference sediments. No bioaccumulation exceedances for Cd, Cr, Cu, Ni, or Zn were measured. NAVPHIBASE LCREEK Tributaries sediment caused clams to bioaccumulate a level of Hg that exceeded both bay and ocean reference sediment bioaccumulation values, but this exceedance was not statistically significant. Pb bioaccumulated by organisms exceeded the ocean reference but not the bay reference. This difference was statistically significant.

144. Clams exposed to NAVPHIBASE LCREEK Tributary sediments, as well as clams exposed to both bay and ocean reference sediments, were analyzed for PAHs. The results of the residue determinations indicated that there was no evidence of bioaccumulation in the samples. No PAH residues obtained for any of the samples were above the analytical detection limit of 10 $\mu g/g$.

145. At the present time there is no reason to believe that disposal of the test sediments will cause significantly greater bioaccumulation than

background. No exceedances were demonstrated for PAHs, and a single sediment had a statistically insignificant exceedance for Hg, as well as an exceedance for one of the reference sediments. The average bioaccumulation concentration of each analyte for all of the test sites was always less than that for either reference site, although in some cases the difference was not statistically significant.

146. In the single case where Pb was significantly bioaccumulated in NAVPHIBASE LCREEK Tributary sediment as compared to the ocean reference sediment, this exceedance is not considered to have toxicological significance. The level of bioaccumulation shown by clams exposed to this sediment was more than an order of magnitude lower than a tissue level associated with any known toxic effects. Dillon (1984) discussed the levels of metals bioaccumulation in relation to toxic effects and reviewed the literature to establish the highest "no effect" concentration and the lowest "effects" concentration. None of the values obtained for bioaccumulation in the tests in the present study approach the levels reported by Dillon. Therefore, there is no reason to believe that the sediments tested in the present study are unsuitable for open-water disposal at any of the sites under consideration from the standpoint of bioaccumulation of contaminants.

Modeling Short-term Behavior During Disposal

Model description

147. A numerical model was used to predict the short-term fate of dredged material disposed at open-water sites, that behavior which is influenced by the physical processes occurring within the first few hours after the discharge. The model provided estimates of water column concentrations of suspended sediment and contaminant, and the initial deposition of material on the bottom.

148. Since the water column elutriate testing did not indicate contaminant release above Federal criteria, modeling was not required to assess the acceptability of open-water options. Rather, the model results were used to compare the initial mixing characteristics of the sites and to gain information regarding the deposition of material on the bottom. The placement of material from NWS Yorktown, CAX, and NAVPHIBASE LCREEK Tributary was modeled at each of the seven open-water disposal sites for a total of 21 model runs. Since the NAVPHIBASE LCREEK sediment was predominantly sand, and the critical

behavior for plume dispersion is governed by the fine-grained material, no separate model runs were made for the NAVPHIBASE LCREEK Channel material.

149. Three models are available for use in such predictions. Two of the models were developed by Brandsma and Divoky (1976) under the Corps Dredged Materials Research Program to handle both instantaneous dumps and continuous discharges. The models were based on work performed for EPA by Koh and Chang (1973). A third model, which utilized features of the two earlier models, was constructed later to handle a semicontinuous disposal operation from a hopper dredge. These models are known as DIFID (DIsposal From an Instantaneous Dump), DIFCD (DIsposal From a Continuous Discharge), and DIFHD (DIsposal From a Hopper Dredge). Personal Computer (PC) versions of the models are available as a part of the Automated Dredging and Disposal Alternatives Management System (ADDAMS) (Schroeder and Palermo 1990) and will be incorporated in the implementation manuals for both Section 103 and Section 404 dredged material discharges (US Environmental Protection Agency/US Army Corps of Engineers 1990).

150. In all three models, the behavior of the material is assumed to be separated into three phases: convective descent, dynamic collapse, and passive transport-dispersion. These models simulate movement of the disposed material as it falls through the water column, spreads over the bottom, and finally is transported and diffused as suspended sediment by the ambient current. The use and limitations of the models, along with theoretical discussions, are presented in detail in Johnson (1990). For the evaluations of open-water alternatives for this study, only mechanical dredging and discharge from hopper barges were considered. Therefore, only the DIFID model was used.

Model input

151. Input data for the models is grouped into the following general areas: (a) description of the disposal site, (b) description of the disposal operation, (c) description of the dredged material, (d) model coefficients, and (e) controls for input and output.

152. Model input for disposal site. The model input to describe the disposal sites includes a description of data on disposal site water depths, current velocities, and density stratification over a computational grid. The site characteristics used for all seven disposal sites modeled are shown in Table 4. Representations of each site and computational grids are shown in Figures 12 through 18. The present water depth at each site was used in the

model runs. The depths were taken from the most recent bathymetric surveys conducted at active sites, or, in absence of surveys, from the most recent Coast Guard charts. For all sites, the bathymetry indicated that an assumed constant depth would be sufficient for the runs.

153. Model input for disposal operation. The description of the disposal operations for the DIFID model includes position of the disposal barge on the grid, the barge velocity, dimensions, draft, and volume of dredged material to be discharged. The same dredging equipment configuration and operation were assumed for all runs for purposes of comparison. A 2,000-cu-yd hopper barge, with dimensions of 100 ft length, 50 ft width, and 5 ft unloaded draft was assumed. The barge was assumed to be at rest at the time of discharge. The position of the discharge point for the barge at each site is shown on Figures 12 through 18. The discharge points were selected to coincide with the present management plan for the presently active sites. For all presently inactive sites, the discharge point was selected at the center of the site.

154. Model input for dredged material properties. The dredged material is modeled as a number of solid fractions, a fluid component, and a conservative contaminant. The input data for each solid fraction must include a volume concentration (calculated from the percent of the fraction by weight and the aggregate void ratio or density), a specific gravity, a settling velocity, a void ratio for bottom deposition, and information on whether or not the fraction is cohesive. For these runs, a sand fraction and a silt/clay fraction were modeled. Data for void ratio, grain size distribution, and Atterberg Limits used to derive the model data were assumed as the average of all samples collected for the four sediment types modeled as shown in Table 2. It was also assumed that all the solids in the discharge were completely noncohesive, which is a very conservative assumption.

155. The standard elutriate test indicated that no specific contaminant was released at concentrations exceeding EPA acute marine criteria, therefore no specific contaminant was modeled. Rather, the fluid phase of the dredged material was modeled for comparison of the mixing characteristics at each of the sites, with results expressed as a percentage. The fluid phase is equivalent to the dredged material suspended phase as defined for water column bioassays (US Environmental Protection Agency/US Army Corps of Engineers 1990); i.e., the liquid phase plus fine suspended particles at concentrations which would allow test organisms to be visible during the bioassay. From a modeling

standpoint, the dredged material suspended phase so defined would behave identically with the liquid phase.

156. Model coefficients. Coefficients are required for the models to accurately specify entrainment, settling, drag, dissipation, apparent mass, and density gradient differences. The available default values were used for all model runs.

Modeling results

157. Descent and accumulation. The descent behavior was similar for all model runs at all sites and for all materials. The vast majority of the dredged material descended to the bottom within a few seconds after discharge, and accumulated on the bottom near the point of discharge. A portion of the clay silt fraction accumulated over a wider area around the point of discharge. Model results showing the footprint of the area of deposition after 1 hr for the NWS Yorktown material placed at the Naval Channel site are shown in Figure 20 and are typical of these results for all model runs.

158. Initial water column mixing. The model results are in terms of concentrations over the model grid at specified water column depths and elapsed times after discharge. The plumes for the sand fraction, clay-silt fraction, and fluid fraction of the dredged material were modeled at three water depths: (a) near surface, (b) mid-depth, and (c) near bottom for each material and each site. For all materials and all sites, the sand fraction had completely settled to the bottom within approximately 10 min after discharge. The plumes for the clay-silt fraction and fluid fraction were dispersed over time with the plume centroid advected by the current. Model results for the Naval Channel site showing the plume concentrations for the clay-silt phase at mid-depth after 1 hr are shown in Figure 21 and are typical of the results for all model runs.

159. For purposes of comparison between materials and sites, the maximum concentration of silt-clay over the entire grid after the period of initial mixing and the maximum concentration outside the boundary of the disposal site after the period of initial mixing are summarized in Table 13. Since the initial water content and percent of sand and clay-silt for NWS Yorktown and CAX were so similar, the model results for these materials were identical.

160. With the exception of the Naval Channel site, which had a maximum observed plume concentration of 1,138 mg/ℓ, the maximum concentration of clay-silt in the plumes for all sites and all materials was generally below 100 mg/ℓ. It should also be emphasized that these predictions are extremely

conservative due to the assumption of no cohesion. The maximum observed concentrations of the fluid phase are shown in Table 14.

Modeling Long-term Mound Stability

161. It is necessary to ascertain whether dredged material placed in open-water sites will remain within the designated site boundaries, or whether such material may be dispersed onto sensitive biological regions. Open-water disposal consists of placing dredged material into a body of water using hopper dredges, or dredge scows or barges, and allowing the material to settle into a stable mound on the bottom. The placement of dredged material by this method can be numerically simulated if certain pertinent environmental parameters and material characteristics can be determined. A critical hydrodynamic parameter regarding the long-term stability of the disposal mound after the material comes to rest is the ambient background water current velocity which may disperse the material from the mound following initial settlement to the bottom. The technical literature has been perused to determine existing knowledge pertaining to typical non-storm velocities representative of those expected during disposal operations at the seven open-water sites being considered for dredged material disposal.

Grain size considerations

162. It is proposed to dredge material from four different locations. Based on sample gradation curves, the average D_{50} grain sizes for these four locations are shown in Table 15. Because the coupled hydrodynamic/sediment transport model used to compute the long-term fate of the disposed material is strictly applicable only to non-cohesive materials, the lower limit of average D_{50} grain size is taken to be 0.0625 mm. The resulting simulations will be conservative, as finer cohesive silt or clay materials will not disperse as rapidly as fine sand. The actual average grain sizes of the material to be dredged from the four locations, the simulation grain sizes, and the volume of material are presented in Table 15.

Assumed mound configuration

163. The tentative size of each of these potential disposal sites is relatively large (Zappi, Palermo, and LaSalle 1990). For relative comparison purposes, and because the minimum area of all potential disposal sites is at least 1.0 square mile, this dimension of 1.0 square mile has been used in the numerical simulation model for all seven disposal sites. If the total volume

of material to be dredged from the four areas over 50 years (4,880,000 cu yd) is considered to be placed in any one of the seven potential dredged material disposal sites at a uniform depth over a 1.0-square-mile area, the average depth of disposed material in the sites would be approximately 5.0 ft.

Hydrodynamic considerations

164. The hydrodynamic forcing functions contributing to the dispersion of material from the disposal sites includes the alternating velocities associated with the astronomical tides, and the unidirectional currents which are associated with riverine flows into the Chesapeake Bay. Riverine and rainfall inflows to the bay are reflected as a net outward flow down the Chesapeake Bay toward the Atlantic Ocean. This in turn constitutes a residual long-term velocity component contributing to dispersion in the absence of disposal site armoring processes not accounted for in the numerical simulation model. The tidal amplitude, tidal velocity components, and superimposed riverine velocity magnitudes are obtained from the verification studies of the Chesapeake Bay physical model (Scheffner et al. 1981).

165. The average long-term tide amplitudes necessary for numerical model simulation of dispersiveness, the average long-term tidal velocity amplitudes necessary for initiating and sustaining movement of disposed dredged material, and the average residual long-term velocities which produce a net movement of disposed dredged material are presented in Table 16.

Length of numerical simulations

166. Average hydrodynamic condition simulations. For relative comparison purposes, the coupled hydrodynamic/sediment transport model provided simulations of dispersion from the seven potential dredged material disposal sites for a 3-month time period under the assumption that dredged material from each of the four prospective dredging areas was placed in each of the disposal sites. This required 28 distinct simulations, each of 3-month's duration.

167. Northeaster 48-hr storm condition simulations. To ascertain a relative comparison of the effects of an average northeaster storm on dispersion from the seven potential dredged material disposal sites, a 48-hr-duration storm condition was superimposed on the average long-term hydrodynamics produced by the astronomical tides and riverine inflow. The northeaster results in a separate velocity component which is vectorially additive to the astronomical velocities. The northeaster velocity is estimated to have a maximum amplitude of about 2.0 ft/sec, and will arise and decay in a sinusoidal manner. This additional northeaster velocity of 2.0 ft/sec

was simulated for the 28 prospective dredging area/disposal site combinations for a 48-hr-duration storm to ascertain the relative dispersion of the disposal mounds under storm conditions.

Numerical simulation model

168. General considerations. The long-term simulation phase of the relative evaluation of dispersiveness with average hydrodynamic conditions investigates the behavior of the dredged material mound over long periods. This analysis results in a means of classifying disposal sites as either dispersive or non-dispersive, based on whether local velocity fields are adequate to erode and transport significant amounts of material from the site. The local currents can be due to either normal tidal action and mean flow circulation patterns, or riverine contributions which give rise to a net outward component of flow which may induce a long-term general transport of material down gradient. The northeaster 48-hr storm condition simulations perform a relative evaluation under the assumption that a typically representative storm event is superimposed on the average hydrodynamic conditions.

169. Both the long-term and storm simulation analyses begin with the assumption that the short-term disposal operations are successful in creating a stable mound configuration. Whether the mound is dispersive or non-dispersive depends on whether the local current conditions are capable of resuspending and transporting significant amounts of material from the mound in such a way that areas adjacent to the disposal site are adversely impacted.

170. The long-term site stability analysis and the storm event simulations both utilize the current time history to provide a quantitative estimate of the stability of the mound as a function of localized environmental conditions. The analysis approach is based on coupled hydrodynamic and sediment transport models which compute the transport of non-cohesive sediment as a function of the local velocity and depth (Scheffner 1989, 1990). The resulting distribution of transport is used in a sediment continuity model to compute changes in the bathymetry of the sediment mound. Bathymetry change computations were made at every 3-hr time-step, for a 3-month period.

171. Data requirements. Site stability methodology is dependent on accurate prediction of sediment transport at the local site under investigation. Empirical relationships for computing sediment transport as a primary function of depth-averaged water velocity, local depth, and sediment grain size were initially reported by Ackers and White (1973), and subsequently modified (Swart 1976) to reflect an increase in sediment transport rate when

the ambient currents are accompanied by surface wave fields. This additional transport reflects the fact that wave-induced orbital velocities are capable of resuspending bottom sediments, independent of the sediment put into suspension by mean currents. The total amount of sediment put into suspension by waves and currents is then transported by the ambient current field.

172. The modified Ackers-White relationships are used to compute the transport of uniformly graded non-cohesive sediment in the grain diameter range of 0.04 mm to 4.00 mm (White 1972). The averages of the D_{50} values for the four prospective dredging areas were 0.006 mm (CAX), 0.008 mm (NWS Yorktown), 0.140 mm (NAVPHIBASE LCREEK Tributaries), and 0.200 mm (NAVPHIBASE LCREEK), being in the range of fine sand to silt or clay. The sediments from CAX and NWS Yorktown are below the lower limit of applicability of the Ackers-White relationships. Therefore the D_{50} grain size is taken as 0.0625 mm, which is about the lower limit of sand-sized particles. Since the sediments do contain approximately 10 percent non-cohesive material, this approximation can be used to give a reasonable estimate of total transport (Kamphuis 1990). The resulting relative comparison simulations will be conservative, as finer cohesive silt or clay materials will not disperse as rapidly as fine sandy materials. Hence, for relative evaluation purposes, the grain sizes selected for numerical simulation were 0.0625 mm (CAX and NWS Yorktown), 0.140 mm (NAVPHIBASE LCREEK Tributaries), and 0.200 mm (NAVPHIBASE LCREEK Channels).

173. Computed sediment transport versus depth-averaged velocities for a range of depths corresponding to those of interest at the seven potential disposal sites (20-ft through 70-ft depths) are shown in Figures 22 through 24 for D_{50} grain sizes of 0.0625 mm, 0.140 mm, and 0.200 mm, respectively.

174. The final data input requirement is that of specifying the geometric configuration of the disposed sediment mound. The worst-case scenario exists if it is assumed that the entire 50-year disposal volume (4,880,000 cu yd) is placed instantaneously at any one potential disposal site. For relative comparison purposes, all disposal sites are considered to have the same dimensions. From historical evaluations of existing disposal sites around the nation, a disposal mound 5 ft high is not unrealistic. Hence, a square disposal site with side dimensions of 5,000 ft and a height of approximately 5 ft will accommodate the anticipated 50-year disposal volume. These dimensions were selected as the evaluation mound configuration for both long-term average hydrodynamic condition simulation comparisons and 48-hr northeaster storm event condition simulation comparisons. A three-dimensional

perspective view and contour map of the type of disposal mound used for each site are shown in Figures 25 and 26, respectively. These figures from the Naval Channel site are for illustration of dimensions only, and the actual elevations will vary for each individual site.

Material dispersion from the disposal sites

175. The dispersion of dredged material from the seven potential disposal sites is indicated by movement of the centroid of the disposal mounds after the simulation periods. A quantitative assessment of mound stability is made by computing the location of the centroid of the mound along the central mound axis for each computational time step of the simulation. These computations are made by balancing the summation of moments at each computational grid. The stability analysis is made by estimating mound response to long periods of exposure to the average hydrodynamic conditions (3-month simulations). In addition to this normal condition simulation, a storm event analysis was performed to investigate single event erosion of the test mound. A 48-hr northeaster storm event was selected as typically representative of storm events for this region of the nation.

176. The Naval Channel potential disposal site is selected as an example of a worst case scenario of the long-term simulation mound axis migration history for a disposal site, after receiving all disposed material with either NWS Yorktown or CAX dredged materials covering the disposal mound. The mound migrations and contour maps for this site after 3 months (2,088 hr) are shown in Figures 27 and 28. The time-history of the centerline axis movement over the 3-month time period is shown in Figure 29.

Summary conclusions

177. Results of all of the relative comparison simulations of disposal mound centroid movement are presented in Table 17. All seven of the potential disposal sites would experience a minimal degree of disposal mound centroid movement under 48-hr northeaster storm events. The greatest amounts of centroid movement for a single 48-hr storm would occur at the Dam Neck site if this mound were covered with fine material dredged from either NWS Yorktown or CAX, and at the shallow Thimble Shoal site if this mound consisted of material from any of the four prospective dredging areas. The water depth at this location is sufficiently shallow (22 ft) such that the average current magnitude is great enough to transport material during most of the tidal cycle. It appears from relative comparisons of the seven potential disposal sites under

48-hr northeaster storm event simulations that no site is significantly different from another under these conditions.

178. Dispersiveness is a subjective determination based on the actual amount of movement experienced by the disposal site mound after experiencing certain hydrodynamic forces for a finite time increment. The disposal mound boundaries spread to a greater lateral extent with a corresponding decrease in mound thickness. All volumetric quantities of materials are accounted for in the mass continuity balance.

179. For purposes of this relative comparison analysis, those sites which experience less than 100 ft of centroid movement during a 3-month time increment are considered non-dispersive. Sites which experience centroid movement between 100 ft and 500 ft during a 3-month time increment are considered moderately dispersive. Sites which experience centroid movement greater than 500 ft during a 3-month time increment are considered dispersive. Accordingly, the proposed Norfolk disposal site, Naval Channel disposal site, and Rappahannock disposal site would be dispersive if the mound was covered with material dredged from either NWS Yorktown or CAX. The Thimble Shoal disposal site would be considered dispersive for all four types of dredged material. The proposed Dam Neck and York River disposal sites would be non-dispersive if the disposal mound was covered with any of the four dredged materials. The proposed Norfolk, Wolf Trap, and Rappahannock disposal sites would be non-dispersive if the disposal mound was covered with material from either NAVPHIBASE LCREEK Tributaries or Channels. The proposed Naval Channel disposal site would be considered moderately dispersive if the disposal mound was covered with material from either the NAVPHIBASE LCREEK Tributaries or Channels. The proposed Wolf Trap disposal site would be moderately dispersive if the disposal mound was covered with material from either NWS Yorktown or CAX. This dispersiveness interpretation is displayed in Table 18.

Cost Estimates

180. A comparative cost estimate for placement of materials from the four prospective dredging areas dredged at each of the disposal sites under consideration was prepared by the Norfolk District as shown in Table 19. These estimates were prepared using the same procedures as those used for preparing official estimates for bid purposes. However, all the estimates were based on planning-level information and are therefore conservative. The

estimates include mobilization, demobilization, direct dredging costs, and contingencies. The unit costs for Craney Island included an additional \$2.35/ yd^3 for removal of material from the handling basin. As would be expected, the unit cost generally increased with increasing haul distance and decreased with increasing volume to be dredged. However, the costs for all options were generally within a factor of two and were comparable with the cost for transporting the material to the Craney Island disposal facility.

Assessment for Open-Water Disposal

Environmental assessment

181. Suitability of materials for open-water disposal. Under the Management Strategy, the suitability of placement of a given material at an open-water site from the standpoint of contaminants is evaluated in light of potential water column and benthic effects. Federal criteria for MPRSA Section 103 (US Environmental Protection Agency/US Army Corps of Engineers 1990) were used to assess the suitability of material for disposal in both the ocean and Bay sites evaluated as a part of this LTMS study.

182. Water column toxicity. Potential water column contaminant effects can be evaluated in light of the Federal acute marine water quality criteria (tier II) or water column bioassay results (tier III), considering initial mixing. The period for initial mixing for ocean sites is 4 hr. For bay sites, an initial mixing period of 1 hr was selected to more closely coincide with the likely frequency of discharges at the nearby bay sites. Using the tiered approach, the water column contaminant impacts were evaluated based on a comparison of standard elutriate test results with Federal acute marine water quality criteria. Since the tests indicated that no contaminant release would exceed the criteria, all the materials are suitable for disposal at any of the open-water sites from the standpoint of water column contaminant effects.

183. Additional insight regarding the suitability of the materials from the standpoint of water column contaminants can be gained by examining the initial mixing characteristics of the disposal sites. If Tier III water column bioassays were to be conducted, a value of 0.01 of the 96LC50 (in percent) is compared to the concentration (in percent) of the dredged material suspended phase following initial mixing. The short-term-fate modeling indicated the concentrations of the dredged material suspended phase were below

1 percent for all materials at all sites. This further indicates that there is little potential for water column contaminant effects.

184. Benthic toxicity. Potential benthic effects are evaluated in light of benthic bioassays, considering both potential benthic toxicity and bioaccumulation. The toxicity criterion for benthic bioassays is statistically significant toxicity at least 20 percent greater than that of a reference sediment. The benthic toxicity tests indicated no significant differences between materials from the prospective dredging areas and either of the two reference sites in terms of *Neanthes* survival. On the basis of these results, all the materials are suitable for disposal at any of the open-water sites from the standpoint of benthic toxicity.

185. Benthic bioaccumulation. The criterion for benthic bioaccumulation is statistically significantly more bioaccumulation than that from a reference sediment. The benthic bioaccumulation tests indicated no significant bioaccumulation of PAHs in the materials from the prospective dredging areas and either of the two reference sites. On the basis of these results, all of the materials are suitable for disposal at any of the open-water sites from the standpoint of PAH bioaccumulation.

186. Physical impacts on sensitive resources. The screening criterion for potential physical effects of open-water disposal on sensitive resources in the vicinity of the sites was the existence of commercial fish or shellfish leases within 1 mile of a site. If such a lease existed, the site would be dropped from further consideration. This criterion is based on the assumption that water column suspended solids concentrations outside the site boundaries would be low and that material accumulation on the bottom would occur within the site boundaries. Inquiries to the Virginia Marine Resources Commission indicated no such leases existed within a mile of any of the sites under consideration.

187. Modeling results indicated that the maximum observed water column suspended solids concentrations outside the site boundaries would generally be below 100 mg/ℓ. The bottom accumulation was projected to occur within the site boundaries for all materials at all sites. Based on these considerations, all sites are acceptable from the standpoint of potential physical impacts on sensitive resources.

188. Accumulative versus dispersive sites. Open-water disposal sites can be described as predominantly accumulative or dispersive. At accumulative sites, most of the material remains on the bottom, forming mounds and

remaining at that location. At dispersive sites, most of the material is dispersed over time and transported away from the site by currents. For the Phase II evaluation, a criterion was established that an acceptable site must be predominantly accumulative. This was defined for this study to mean that the vast majority of the material would quickly descend to the bottom upon discharge, forming a mound, and that the mound would not experience significant long-term erosion or migration.

189. The short-term modeling results indicated that all materials at all sites would quickly descend to the bottom within the site boundaries. The long-term modeling indicated that the Thimble Shoal site was dispersive for all materials; therefore, it is not an acceptable site from the standpoint of long-term mound stability. The Norfolk, Naval Channel, and Rappahannock Shoal sites were dispersive for the NWS Yorktown and CAX materials; therefore, these sites are also unacceptable from the standpoint of long-term mound stability.

Engineering assessment

190. Engineering criteria are those concerned with the design, construction, and operational practicability of a dredging or disposal alternative. Engineering criteria would be met if the site under consideration was not constrained by haul distance or placement techniques linked to constraints on equipment capability (e.g., available ocean-going tugs, sea state constraints, limits on navigation accuracy, etc.) These were considered in the site designation studies for the Dam Neck and Norfolk ocean sites. Disposal operations have been successfully carried out at all the bay sites in the past using readily available equipment, and there is no indication that unusual safety considerations would preclude them.

191. An additional engineering criterion is that the use of a given site should not conflict with other intended users or established management plans for the site. The Dam Neck, Rappahannock Shoal, and Wolf Trap sites are the only sites under consideration which have established management plans or specified long-term anticipated use for maintenance for other navigation projects. The volumes of material to be dredged by the Navy are quite small compared to the volumetric capacities of the disposal sites. Based on these considerations, use of any of the open-water sites for any of the materials is acceptable from an engineering practicability standpoint.

Economic assessment

192. No specific criteria for economic practicability were used for this study. Since the costs for all open-water disposal options were

generally within a factor of two and were comparable to the cost of transporting the material to the Craney Island facility, all open-water options were considered practicable from the standpoint of costs.

Practicability summary for open-water disposal

193. Table 20 summarizes the practicability of open-water disposal options with respect to environmental, engineering, and economic criteria. All sites were determined to be practicable from engineering and economic standpoints. The Thimble Shoal site was determined to be not environmentally practicable for placement of materials from all four of the prospective dredging areas because of its dispersive characteristics. The Naval Channel and Rappahannock Shoal Alternate sites were determined to be environmentally practicable for NAVPHIBASE LCREEK Tributary and Channel materials but not practicable for placement of NWS Yorktown and CAX materials because of dispersive characteristics. The Dam Neck, Norfolk, York River, and Wolf Trap Alternate sites were determined to be practicable with respect to all criteria.

PART V: ASSESSMENT OF CONFINED DISPOSAL OPTIONS

General

194. It is likely that some of the material from the prospective dredging areas may be found to be unsuitable for open-water disposal in the future, and the LTMS must provide for a disposal alternative for such material. For purposes of this LTMS, it is assumed that 10 percent of the total volume of material from NWS Yorktown, CAX, and NAVPHIBASE LCREEK Tributaries may be found to be unsuitable for open-water disposal. The assumption of 10 percent was used to assess the acceptability of CDF sites from the standpoint of volumetric capacity and should ensure that adequate disposal capacity for potentially unsuitable material is provided. Several options can be considered for disposal of such unsuitable material to include capping and disposal in CDFs. Capping is a disposal alternative which involves placement of unsuitable material at an open-water site, followed by placement of clean material to form a covering or cap. However, capping has not been used in the Cheasapeake Bay in the past, while CDFs have been commonly used for disposal of material unsuitable for open-water disposal. Further, CDFs have been used for disposal at the NWS Yorktown and NAVPHIBASE LCREEK in the past. CDFs are therefore a logical option for material unsuitable for open-water disposal, assuming CDF capacity is available.

195. An assessment of the practicability of CDF options was made based on the results of laboratory tests and limited site investigations. The confined site evaluation included two sites on NWS Yorktown property and three sites on NAVPHIBASE LCREEK property deemed suitable for construction of CDFs. Hydraulic filling from pipeline dredges or hydraulic offloading from barges was the assumed method of placement of material for the confined sites.

196. The assessment of CDF options consisted of the following:

- a. Site investigations to determine general suitability for construction and operation of CDFs.
- b. Column settling tests to determine the CDF design requirements for retention of suspended solids and initial storage volume during filling.
- c. Consolidation tests used to estimate the long-term storage capacity of the sites.
- d. Modified elutriate tests to determine the quality of effluent discharged from the CDFs during filling.

e. Evaluation of the potential for leaching of contaminants to groundwater based on chemical partitioning analysis.

Considerations for Confined Disposal

197. CDFs are used to retain dredged material solids while allowing the carrier water to be released from the containment area. The two objectives inherent in the design and operation of a CDF are to provide adequate storage capacity for the volume of material to be dredged and to attain the highest possible efficiency in retaining solids during the dredging operation in order to meet effluent suspended solids requirements. These considerations are basically interrelated and depend upon effective design, operation, and management of the containment area.

198. In most CDFs, constructed dikes form a confined surface area, and the dredged channel sediments are normally pumped into this area hydraulically. Both the influent dredged material slurry and effluent water can be characterized by suspended solids concentration, suspended particle size gradation, type of carrier water (fresh or saline), and rate of flow.

199. In some dredging operations, especially in the case of new dredging, sand, clay balls, and/or gravel may be present. This coarse material (greater than the No. 200 sieve) rapidly falls out of suspension near the dredge discharge pipe, forming a mound. The fine-grained material (less than the No. 200 sieve) continues to flow through the containment area with most of the solids settling out of suspension, thereby occupying a given storage volume in the CDF. The fine-grained dredged material is usually rather homogeneous and is easily characterized.

200. The clarified water is usually discharged from the containment area over a weir. Effluent flow rate is approximately equal to influent flow rate for continuously operating disposal areas. Flow over the weir is controlled by the static head and the weir length provided. To promote effective sedimentation, ponded water is maintained in the area with the depth of water controlled by the elevation of the weir crest. The thickness of the dredged material layer increases with time until the dredging operation is completed. Minimum freeboard requirements and mounding of coarse-grained material result in a ponded surface area smaller than the total surface area enclosed by the dikes.

201. In most cases, confined disposal areas must be used over a period of many years, storing material dredged periodically over the design life. Long-term storage capacity of these areas is therefore a major factor in design and management. Consolidation of the layers continues for long periods following disposal, causing a decrease in the volume occupied by the layers and a corresponding increase in storage capacity for future disposal. Once water is decanted from the area following active disposal, natural drying forces begin to dewater the dredged material, adding additional storage capacity. The gains in storage capacity are therefore influenced by consolidation and drying processes and the techniques used to manage the site both during and following active disposal operations.

Potential Confined Disposal Sites

Suitability of sites for disposal operations

202. All potential CDF sites at NWS Yorktown and NAVPHIBASE LCREEK identified in the Phase I study were investigated in Phase II. An initial assessment of suitability was made based on limited site investigations and detailed topographic maps furnished by the Navy.

203. The Phase I Report (Zappi, Palermo, LaSalle 1990) listed five potential CDF sites at NWS Yorktown. They were as follows: the Magazine 13/14 site, the Lee Pond site, the Roosevelt Pond site, the Old Disposal site, and the Landfill/Forest site. The locations of these sites on NWS Yorktown property are shown in Figure 3. During an onsite investigation in May 1990 three of the five sites were deemed unacceptable, or at least impractical, for use at the present time because of environmental reasons. The Lee Pond site and the Roosevelt Pond site were both considered environmentally unacceptable because of nearby spring-fed streams and freshwater wetlands and because of their existing or potential use as recreational facilities. The Old Disposal site is now covered by freshwater wetlands that developed on the previously disposed dredged material. Cattails and other aquatic plants were more than 6 ft high at this site. It was felt that, because of current national policy, any site which involves wetlands should be avoided, if there are practical and economical alternatives.

204. In addition to these three sites, the old landfill portion of the Landfill/Forest site was deemed to be unacceptable for environmental reasons. There is some preliminary indication, as yet unconfirmed, that hazardous

materials may have been disposed at this site at some time in the past. If this proves to be true, and if these materials have to be excavated and relocated, or if other remediation activities have to be performed on this site, the presence of a CDF on top of the site would present a major problem. The mere possibility of such a situation is enough to rule out this portion of this site.

205. There are two remaining sites at NWS Yorktown on which a CDF could be located. They are the Magazine 13/14 site and the Forest site. Each will be discussed from an engineering suitability standpoint in a separate subsection following. Summary information on all sites is shown in Table 21.

Magazine 13/14 site

206. The Magazine 13/14 site is located south of Turkey Road between Magazine Groups 13 and 14 as shown in Figure 30. The pumping distance from Pier R-3 to this site is approximately 4.2 miles. The effluent from this site would flow into Felgates Creek. The entire site contains approximately 27 acres, but, because of the topographical considerations, the largest CDF which could be placed on this site without major earthwork is much smaller.

207. The elevation of the site ranges from approximately 5 ft at the eastern edge to approximately 80 ft at the southwestern corner. A small unnamed branch flows in a ravine from west to east across the site, exiting through a culvert under Turkey Road near the northeast corner. Most of the northern half of this site consists of the steep-sided ravine containing this branch. In the southwest corner is a small, flatter, plateau-like area, ranging from approximately elevation 50 ft to elevation 75 ft.

208. One method to construct a CDF at this site would be to place a dam across the ravine near the northeast corner and create an impoundment which would effectively cover the entire ravine, up to the drainage divide at Turkey Road at Magazine 14. The dam would have a crest elevation of approximately 50 to 55 ft and would be approximately 350 ft long at the crest. The base elevation of the dam would be approximately 5 to 10 ft. Since the entire length of the ravine would be contained within the impoundment, no surface stream would flow into it, so no diversion around it would be necessary.

209. The surface area of the impoundment would be approximately 8 acres, depending on the water surface elevation chosen. The length would be approximately 1,100 ft, and the average width would be approximately 250 ft. The average depth would be approximately 15 ft, but would vary from zero at the western end to approximately 40 ft at the eastern end. The influent

should be at the western end, with the withdrawal structure at the eastern end.

210. A dam across the ravine would produce the largest surface area, largest depth, and both longest hydraulic detention time and largest sediment storage volume of any of the sites at NWS Yorktown. There could be environmental objections to filling the small stream in the ravine. The hydrology and ecology of the small stream in the ravine are not known, or even whether the stream is perennial or intermittent. However, these environmental factors must be carefully investigated. In addition, the suitability of the onsite soils for construction of a 40- to 50-ft dam would have to be thoroughly investigated.

211. This location does have one advantage that the other sites do not have, however. The high sediment storage volume mentioned earlier could be increased even further, if necessary for long-term management, with minimal dike construction. Dikes would only be necessary at the eastern end, just upstream from the dam, and at the narrow western end, because the long north and south sides rise to natural elevations of 60 to 70 ft.

212. Another construction alternative for this site is to level the plateau on the southwestern corner to a base elevation of approximately 50 ft so the static pumping head would be about 60 ft. This would require excavation of 10 ft to 20 ft of soil at the western edge of the site. This excavated soil could then be used to construct the dikes around the site. A cursory walk-over and examination of surface soils in May 1990 indicated that they were probably sandy clays which should be suitable for construction of dikes in the range of 5 ft to 10 ft in height. The resulting CDF would be approximately 400 ft by 600 ft in size and contain approximately 5 acres. Both the influent and effluent should be located at the eastern end of the CDF, separated by a spur dike. This would place the influent closest to the pier, and it would allow the effluent to drain into a small southern arm of the branch that runs through the center of the entire site.

<u>The Forest site</u>

213. The Forest site is located approximately 500 ft west of Indian Field Road and east-southeast of Indian Field Creek as shown in Figure 31. It is approximately 1.6 miles from the shoreline end of the pier. The total area is approximately 18 acres, but less than half of this would be suitable for a CDF.

214. The elevation at the southeast corner is approximately 45 ft, and the land slopes gradually down in a westerly and northerly direction to approximately 25 ft. From there, the drop is much sharper down to sea level at the banks of Indian Field Creek. A CDF with a base at an elevation of approximately 35 ft and containing approximately 7 acres could easily be constructed on the southeastern corner of the site.

215. The site is currently covered with trees, a large fraction of which are pines planted in 1985, which are now 3 in. to 5 in. in diameter. A cursory walk-over and examination of the surface soils on the sites in May 1990 indicated that the soils are probably sandy clays, which would allow for easy excavation and leveling of the site and which would be suitable for construction of dikes approximately 5 ft to 10 ft in height on the western and northern boundaries. The resulting CDF would probably be approximately triangular in shape, with the influent entering near the northeast corner, the effluent exiting near the western corner, and with two spur dikes to prevent short-circuiting and increase the hydraulic retention time.

216. Depending on how the pipeline from the pier to the site is routed, the pumping distance could range from 1.5 miles to 3.5 miles. The shortest distance would be by Colonial Parkway and Indian Field Road. An alternate route along the road or railroad leading to the pier, across the golf course and Indian Field Road to the site, would be approximately 1.7 miles. Another alternate would be to support the pipe on floats up the York River and Indian Field Creek to the site. This distance would be approximately 3 miles. Another alternate would be to load the contaminated material on barges, carry the barges to the mouth of Indian Field Creek, and pump the material from there. This pumping distance would be approximately 1.6 miles, and the static pumping head would be approximately 40 ft to 45 ft.

Naval Supply Center, Cheatham Annex

217. No potential CDF sites have been found on the CAX. It is assumed that any contaminated material found around the piers at CAX would be disposed of at NWS Yorktown, and would be transported to NWS Yorktown, either hydraulically or by barge.

NAVPHIBASE LCREEK sites

218. The Phase I report (Zappi, Palermo, and LaSalle 1990) listed six potential CDF sites on NAVPHIBASE LCREEK. These were the Desert/Little Creek Cove site, the Rifle Range site, the New Magazine site, the Beach Drive site, the Landfill site, and the Pier 60 site. The locations of these sites on

NAVPHIBASE LCREEK property are shown in Figure 5. An onsite investigation in May 1990 revealed that the New Magazine site and the Pier 60 site are actually contained within the same tract of land. This tract was therefore considered as a single alternative. The Desert/Little Creek Cove site was found to be unsuitable because of impending construction. The Rifle Range site was deemed unsuitable because of potential problems with existing lead contamination. Therefore, three sites will be considered in detail, and each will be described in separate sub-sections to follow.*

Pier 60/New Magazine site

219. This site is located on the south side of Little Creek Cove, to the north of Niles Road and Ricker Road as shown in Figure 32. There are approximately 10 acres in the entire site. The elevation ranges from approximately 15 ft on the southern edge along Ricker Road to sea level on the northern edge. Slopes are gentle, and, with a moderate amount of excavation along the southern edge and construction of a dike along the northern edge, a CDF approximately 300 ft by 800 ft containing approximately 6 acres could easily be constructed. A new parking lot has been sited on the western boundary of the Pier 60/New Magazine site which would reduce the surface area available for CDF construction by approximately 30 percent. Since the site is actually on the banks of Little Creek Cove, pumping distances would be only a few hundred feet, and the static head would be approximately 15 ft.

The Landfill site

220. This site is located south and west of wetlands which border the south side of Little Creek Cove and is north of Amphibious Drive as shown in Figure 33. There are drainage ditches leading to Little Creek Cove on both the east and west ends. The entire site is approximately 14 acres and is at approximately elevation 12 ft and is almost flat. Dikes would probably have to be constructed on all four sides, and should not encroach on the wetlands. The resulting CDF would measure approximately 900 ft by 450 ft, and would contain approximately 9 acres. Hydraulically, the best alternative would be to construct one longitudinal spur dike and arrange both the influent and effluent to enter and exit at the west end near a large drainage ditch.

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* During the review process for this report, environmental issues associated with Installation Restoration (IR) were investigated at the Landfill and Beach Drive sites. These sites will not be available for CDF construction until these issues are resolved. The data developed for CDF evaluations at these sites have been retained in this report.

221. Hazardous wastes were likely placed in this landfill in the past. The Navy has indicated that, until Installation Restoration environmental issues are resolved, the Landfill site will not be available for CDF construction.

Beach Drive site

222. This site is located north of Eleventh Street and south of Beach Drive, northeast of Desert Cove as shown in Figure 34. The Phase I report states that the site "has an area of approximately 20 acres." However, a ball field and recreational area have been built on the eastern part, and the western part consists of a rugged area with sand dunes up to 35 ft high. Between the dunes and the ball field, there is a triangular-shaped area, now used as a pistol and rifle range, which contains approximately 8 acres. It would be possible to construct a CDF in an approximate triangular shape with sides of about 750 ft by 550 ft, and containing approximately 5 acres, on this site. The pumping distance from Desert Cove to this candidate CDF site is much longer than to the other previously mentioned sites, approximately 2,000 ft, and the static head would be approximately 10 ft. The soils in the area are very sandy, so it may be necessary to import soil from another site for the construction of dikes. The Navy has indicated that, until Installation Restoration environmental issues have been resolved, the Beach Drive site will not be available for construction of a CDF.

Column Settling Tests

Approach

223. The CDF design requirements for retention of suspended solids and initial storage volume during filling were determined using the results of column settling tests. Detailed descriptions of the procedures for conducting the tests and analyzing the data are contained in Engineer Manual 1110-2-5027, "Confined Disposal of Dredged Material," (US Army Corps of Engineers 1987). The results of these tests are used to provide information on zone settling rates, sediment consolidation rates, and rates of clarification of the supernatant above the zone settling interface (Montgomery 1978; Montgomery, Thackston, and Parker 1983; Palermo 1986; Palermo and Thackston 1988; Thackston and Palermo 1988). This allows the calculation of minimum required surface areas, the prediction of effluent suspended solids concentrations for various

operating conditions, and the calculation of required initial sediment storage volumes.

224. The data resulting from these column settling tests were analyzed using the techniques found in the above references. The ADDAMS, an interactive PC-based design and analysis system for dredged material management, contains computer programs to perform the required calculations and was used for this analysis.

Sample compositing

225. Since no feasible disposal sites exist on CAX property, material from this prospective dredging area would be placed in a CDF on NWS Yorktown property. For this reason, samples from NWS Yorktown and CAX were composited for purposes of column settling tests. Since the behavior of the fine-grained sediment governs CDF design requirements, only the NAVPHIBASE LCREEK Tributary composite was used for column settling tests.

226. The NWS Yorktown/CAX composite had an initial water content of 216.72 percent and an assumed specific gravity of 2.68. The column slurry was prepared using 80 lb of the composited sediment, 52 ℓ of tap water, and 936 g of salt. The prepared slurry had a salinity of 18.5 ppt. The NAVPHIBASE LCREEK composite had an initial water content of 169.41 percent and an assumed specific gravity of 2.68. The column slurry was prepared using 72 lb of the composited sediment, 55 ℓ of tap water, and 1,100 g of salt. The prepared slurry had a salinity of 20 ppt.

Compression settling test results

227. In the compression settling test, the height of the interface between the clarified supernatant and the consolidating sediment is measured for a period of 15 days. An equation is fit to the time-height data, and this equation is used to predict the volume of settled dredged material at the end of the active filling portion of the project. The results for the NWS Yorktown/CAX sample and the NAVPHIBASE LCREEK Tributaries sample are shown in Figures 35 and 36.

Zone settling test results

228. The zone settling test data are used to determine how fast the interface settles. This indicates how fast the settling solids can be transported downward under the conditions of hindered settling. The zone settling curve for the NWS Yorktown/CAX composite is shown in Figure 37, along with a straight line indicating the steepest part of the curve. This occurs in the first 6 hr, and is 0.16 ft/hr. The initial slurry concentration was 137 g/ℓ.

The curve for the NAVPHIBASE LCREEK Tributaries sample is shown in Figure 38, along with a straight line indicating the steepest part of the curve. This occurs in the first hour, and is 0.13 ft/hr. The initial slurry concentration was 130.3 g/ℓ.

Flocculent settling test results

229. The flocculent settling data are used to help predict the concentration of suspended solids that would be discharged over an outlet weir from a CDF under specified conditions of flow, CDF geometry and detention time, and weir geometry. It is produced from a multi-height, multi-time column settling test. The results of these tests are shown as plots of effluent suspended solids versus retention time for several ponding depths. The effluent suspended solids concentration will be less if the detention time of the CDF is increased, either by increasing the surface area, the ponded depth, or the hydraulic efficiency. It will also be less if the water is withdrawn from the CDF in a thinner surface layer, from which more solids have settled. Figures 39 and 40 show the relationship between effluent solids concentration and retention time, for each of three values of average withdrawal depth. Weirs can be designed to limit the withdrawal depth, although they are larger and more expensive.

Design Requirements for Retention of Solids and Initial Storage

Project data and assumptions

230. Before calculations of the behavior of the dredged material in a CDF can be made, several assumptions concerning the project and the CDF must be made. These involve the geometry and hydraulic behavior of the CDF, the type of dredging and pumping equipment to be used, and the operating schedule.

231. For the purpose of this study, it is assumed that a typical dredging project at NWS Yorktown will involve the removal of 200,000 cu yd, of which 10 percent, or 20,000 cu yd, is contaminated to such an extent that it must be contained in a CDF. It is likewise assumed that a typical dredging project at NAVPHIBASE LCREEK will involve the removal of 140,000 cu yd, of which 10 percent, or 14,000 cu yd, is contaminated to such an extent that it must be contained in a CDF. Since none of the sediments sampled during this study proved to be contaminated, and there are no current sources of contamination (except for the possibility of accidental spills), this is probably a conservative assumption.

232. It is assumed that the dredging at all the prospective areas will be done by clamshell dredges, with the sediments loaded into barges, because the great bulk of the sediments will have to be disposed of at a distant site. It is also assumed that the clean sediments would be taken to another location for open-water disposal, while pockets of contaminated sediments will be loaded into separate barges. These contaminated sediments will then be reslurried if necessary and pumped to a CDF.

233. The use of a separate cutterhead dredge to excavate the contaminated sediments and pump them directly to the CDF was considered, but this scenario is impractical for two reasons. First, the use of a separate dredge to handle such a small amount of material would be inefficient and expensive. The smallest cutterhead dredge that could reach the 30- to 40-ft depths necessary in the prospective dredging areas would be a 12-in. dredge, and it could dredge only 20,000 cu yd in 2-3 days. It would not be efficient to bring in a separate dredge for this small amount of work. Second, the output of a 12-in. dredge is about 10-12 cfs, and it will be shown subsequently that the maximum flow rate which can be practically accommodated in a CDF of 5-8 acres is about 3 cfs. Therefore, it is assumed that the sediments would be pumped to the CDF using an 8-in.-diam pipeline flowing at a maximum velocity of 8 ft/sec. This produces a flow rate of 2.8 cfs, and would require 10-12 days working 18 hr/day to transfer 20,000 cu yd. Any other combination of pipe diameters, velocities, and pumping schedules that produces this same approximate flow rate would result in approximately the same effluent quality. If, at some time in the future, enough contaminated sediments were discovered to make the use of a cutterhead dredge efficient, it could be used as long as the daily average discharge were kept to approximately 3 cfs. This could be done by only dredging intermittently.

234. With respect to the configuration of all of the alternative CDFs, it is assumed that the height of the dikes would be 10 ft, the minimum freeboard would be 2 ft, the minimum ponded depth would be 3 ft, the hydraulic efficiency of the CDF would be 60 percent, and 90 percent of the original ponded surface area would still be ponded at the end of the disposal period. These are typical and realistic assumptions for all of the possible sites, except for the ravine site at NWS Yorktown, which would require a separate analysis.

Minimum areas and volumes for settling

235. The area required for effective settling depends on the settling characteristics of the sediments, as described by the results of the compression settling test, the zone settling test, and the flocculent settling test. The SETTLE module in the ADDAMS program calculates the minimum surface areas, ponded volumes, and residence times necessary to meet the requirements of all three modes of settling. The designer must use the larger of the three areas.

236. The area required for zone settling is set by the rate at which the sediment solids can be transported downward under hindered settling. It is not a function of sediment depth, ponded depth, or withdrawal depth, but is a function of flow rate. It is also not related to any suspended solids concentration discharge limit. At NWS Yorktown, the minimum area required for zone settling at a flow rate of 2.8 cfs is 2.0 acres. At NAVPHIBASE LCREEK, the minimum required area is 2.46 acres.

237. The area required for flocculent settling is a function of the flow rate, the average withdrawal depth, the retention time, and the suspended solids discharge limit, or target. The State of Virginia currently has no suspended solids limit for dredged material discharges, but the Norfolk District has adopted a self-imposed limit of 5 g/ℓ. The District has also adopted a policy of using Best Management Practices (BMP).

238. Since the initial concentrations of suspended solids in the supernatants above the interfaces in both the NWS Yorktown and NAVPHIBASE LCREEK column settling tests were well below 5 g/ℓ (0.3 g/ℓ at NWS Yorktown and 0.5 g/ℓ at NAVPHIBASE LCREEK), this self-imposed limit could be easily met by any CDF significantly larger than those necessary to meet the area requirements for zone settling (2.0 and 2.5 acres). However, the use of BMP requires that efforts be made to limit the discharge of suspended solids to a practical minimum, so results of analyses showing the suspended solids concentrations in the effluents from the CDFs at the two facilities will be indicated as functions of ponded surface area, depth, and average withdrawal depth.

239. In addition, space must be provided for the initial sediment storage by a combination of ponded area and depth. Analysis of the compression settling test data for NWS Yorktown shows that the required storage volume is 20.84 acre-feet. The depth of sediment at the end of the pumping will vary with the surface area, as follows:

2.60 ft deep for 8 acres
2.98 ft deep for 7 acres

3.47 ft deep for 6 acres
4.17 ft deep for 5 acres
5.21 ft deep for 4 acres
6.95 ft deep for 3 acres
10.42 ft deep for 2 acres

From this data, it can be seen that ponded surface areas at NWS Yorktown less than 5 to 8 acres become impractical, because the excessive depth for initial sediment storage would require dikes greater than 10 ft high.

240. Analysis of the compression settling test data for NAVPHIBASE LCREEK shows that the required storage volume is 13.92 acre-feet. The depth of sediment at the end of pumping will vary with the surface area, as follows:

1.74 ft deep for 8 acres
1.99 ft deep for 7 acres
2.32 ft deep for 6 acres
2.78 ft deep for 5 acres
3.48 ft deep for 4 acres
4.64 ft deep for 3 acres
6.96 ft deep for 2 acres

From these data, it can be seen that ponded surface area at NAVPHIBASE LCREEK less than about 4 to 5 acres would also be impractical, because of the excessive dike heights required, just as at NWS Yorktown.

<u>Retention of suspended solids</u>

241. Although required sediment storage volumes and dike heights will control the designs of CDFs at NWS Yorktown and NAVPHIBASE LCREEK, the designs should also provide for efficient retention of suspended solids. The SETTLE program was used to predict the suspended solids concentrations in the effluents from CDFs with a variety of designs of varying surface areas and average withdrawal depths, all for the assumed maximum flow rate of 2.8 cfs. Figure 41 shows these relationships for the sediment from NWS Yorktown, and Figure 42 shows them for NAVPHIBASE LCREEK sediment. These concentrations were all below 250 mg/ℓ and 400 mg/ℓ for the two sediments, well below the Norfolk District criterion of 5 g/ℓ.

<u>Weir design</u>

242. The outlet weirs should be designed to release water from the surface of the CDF without high velocity approach currents, which might induce scouring of previously deposited sediments. In addition, they should be sufficiently long to allow surface skimming of clarified water without causing

upward currents carrying higher concentrations of suspended solids from near the bottom. They should also be designed so that water is not allowed to leak through the weir structure.

243. The SETTLE module contains a routine to calculate weir lengths which will help insure that these goals are met. Based on these results, it is recommended that weir structures containing at least 12 ft of weir length be used. These can be easily constructed as a 4-ft by 4-ft box weir, which would meet the goal, even with the side adjacent to the dike blocked off.

Design requirements

244. An almost infinite variety of combinations of data from the prospective dredging areas, such as flow rate, ponded depth, withdrawal depth, and suspended solids target can be used to generate minimum areas, and a variety of CDF designs are possible. However, because the available sites limit the practical maximum CDF area, the range of practical designs is limited.

245. An analysis of the results produced by many combinations of data on the prospective dredging areas leads to the recommendations below:

a. The influent flow rate should be limited to approximately 2.8 cfs (8-in. pipe at 8 ft/sec).

b. The surface area ponded at the beginning of dredging should be the total surface area diked.

c. The average ponded depth at the end of pumping should be about 3 ft and should not vary greatly from place to place.

d. The outlet weir should be designed to produce an average withdrawal depth of no greater than 2 ft. A length of at least 12 ft is recommended.

e. The shape of the CDF should be designed so that the hydraulic efficiency is at least 60 percent. This will probably require at least one spur dike.

f. The dikes should be at least 8 ft to 10 ft high to accommodate the required 3 ft to 4 ft of sediment depth, 3 ft of ponded depth, and 2 ft of freeboard at the end of pumping.

Consolidation Tests

246. Self-weight and fixed-ring consolidation tests were conducted on the NWS Yorktown/CAX and NAVPHIBASE LCREEK Tributaries composite samples. These tests provide information related to the consolidation characteristics of the dredged material. The consolidation characteristics of the dredged material are necessary for long-term storage capacity assessment of a CDF. Self-weight and fixed-ring tests provide data for effective stresses between

0 psf and 5 psf, and 18 psf and 1,000 psf, respectively. Self-weight and fixed-ring consolidation data were used to obtain a void ratio-effective stress and a void ratio-permeability relationship for the composited samples (Cargill 1986). Figures 43 through 46 provide the void ratio-effective stress and void ratio-permeability relationships for the NWS Yorktown/CAX and NAVPHIBASE LCREEK Tributaries composite samples.

Long-term Storage Capacity Evaluation

247. Void ratio-effective stress and void ratio-permeability relationships obtained from the consolidation tests are the primary input parameters of the 1990 version of the Primary Consolidation and Desiccation of Dredged Fill (PCDDF90) computer model (Stark, in preparation). PCDDF90 is a numerical computer model that uses a finite strain analysis to predict the surface elevation versus time for various disposal sequences. As discussed previously, 10 percent of the 50-year requirement at NWS Yorktown, CAX, and NAVPHIBASE LCREEK Tributaries was assumed to be unsuitable for open-water disposal and placed in CDF sites. This yields the following dredging requirements:

Location	Material Quantity, cu yd	Dredging Frequency, years
NWS Yorktown	20,000	7
CAX	3,000	5
NAVPHIBASE LCREEK (Tributaries)	14,000	10

248. Using PCDDF90 and the aforementioned dredging requirements, sediment containment analyses were performed on NWS Yorktown's Forest site and NAVPHIBASE LCREEK's Beach Drive site over a 50-year period. Forest and Beach Drive are the smallest disposal sites under consideration at NWS Yorktown and NAVPHIBASE LCREEK. Therefore, if the Forest and Beach Drive sites were determined to have adequate containment capacities for the 50-year dredging requirement, the larger sites would certainly have adequate capacities.

249. Various assumptions were made in analyzing the sediment containment ability of the Forest and Beach Drive sites. First, both sites were assumed to have incompressible foundations. Second, ponded water was assumed to exist between the disposal sequences at both sites; therefore, no desiccation would occur in the upper layer of the dredge fill. Third, rainfall and

evaporation conditions at NWS Yorktown and NAVPHIBASE LCREEK were assumed to be similar to those at Craney Island.

250. The long-term disposal requirements and geotechnical properties of the dredge material suggest lift thicknesses of approximately 2.8 ft every 7 years for NWS Yorktown material and 0.4 ft every 5 years for CAX material for each disposal sequence in the 7-acre Forest disposal site. PCDDF90 predicted a final fill height of 11.1 ft or a final surface elevation of 51.1 ft, with placement of the NWS Yorktown and CAX material. The required dike height for the last disposal sequence would be 14.7 ft; this includes 9.7 ft to contain the dredge fill and 5 ft to contain the ponded water required for sedimentation. A relationship between fill height and time for the Forest site is presented in Figure 47. Assuming incompressible foundations, no desiccation, and similar climatological conditions, PCDDF90 indicated that any of the CDF sites under consideration at NWS Yorktown would meet the long-term storage volume requirements for unsuitable material from NWS Yorktown and CAX.

251. The long-term disposal requirements and geotechnical properties of the dredge material suggest lift thicknesses of approximately 3.2 ft every 10 years for NAVPHIBASE LCREEK Tributary material for each disposal sequence in the 5-acre Beach Drive site. PCDDF90 predicted a final fill height of 14.4 ft or a final surface elevation of 24.4 ft, with placement of the NAVPHIBASE LCREEK Tributary material. The required dike height for the last disposal sequence would be 18.2 ft; this includes 13.2 ft to contain the dredge fill and 5 ft to contain the ponded water required for sedimentation. A relationship between fill height and time for the Beach Drive site is presented in Figure 48. Assuming incompressible foundations, no desiccation, and similar climatological conditions, PCDDF90 indicated that any one of the CDF sites under consideration at NAVPHIBASE LCREEK would meet the long-term storage volume requirements for unsuitable material from the NAVPHIBASE LCREEK Tributaries.

Post-dredging Management Techniques

252. As previously mentioned, it was assumed that no desiccation occurred over the 50-year duration of disposal. This is a conservative estimate based upon little or no post-dredging management. Proper post-dredging management techniques include periodic site inspections and dewatering the fine-grained material (US Army Corps of Engineers 1987). These activities

increase the rate of consolidation by allowing desiccation to occur more efficiently.

253. Once a disposal sequence has been completed and the ponded water has been decanted, site management efforts should be concentrated on maximizing the containment storage capacity gained from continued drying and consolidation of dredged material and foundation soils. Removal of ponded water will expose the dredged material surface to evaporation and promote the formation of a dried surface crust. Weir crest elevations should allow efficient drainage of runoff water. This may require periodic lowering of the weir crest elevation as the dredged material surface settles.

254. Natural processes often need man-made assistance to effectively dewater fine-grained dredged material since dewatering is greatly influenced by climate and is relatively slow. When natural dewatering is not acceptable, additional dewatering techniques, such as trenching, should be considered.

Modified Elutriate Testing

255. In addition to the suspended solids concentrations in the effluents from CDFs, the concentrations of various inorganic and organic chemicals in the effluent must be considered. The chemical quality of effluent discharged during filling operations is assessed by a modified elutriate test (Palermo 1984; Palermo and Thackston 1988a). This test is designed to simulate the physical and chemical behavior of the sediments in the CDF and has been extensively tested and field-validated (Palermo and Thackston 1988b).

256. Modified elutriate tests were run on composite samples for all prospective dredging areas. These tests consisted of mixing sediment and water to a concentration equivalent to that of the hydraulic inflow to the CDF, aerating the mixture for 1 hr, allowing the slurry to settle for a period approximating the expected retention time in the CDF, and extracting a sample of the supernatant water for analysis. The extracted sample was analyzed for both dissolved and particle-associated contaminant concentrations. Based on the results of the sediment chemical inventory, the modified elutriates were analyzed for metals and PAHs, in a manner similar to the standard elutriates.

257. The total concentrations (dissolved plus particle-associated) of seven inorganic contaminants are tabulated in Table 22. Only those parameters that were detected in the modified elutriates are tabulated. None of the PAHs were detected in the modified elutriates. Metals were detected, but were at

concentrations below the Federal acute marine water quality criteria. Since the total concentrations in the modified elutriates were below criteria, separate analysis of the dissolved concentrations was not performed.

Groundwater Leachate Evaluation

258. An assessment of the potential for movement of metals into groundwater below CDFs was made based on conservative equilibrium partitioning principles. This evaluation indicates a worst-case potential for contaminant movement in leachate. It was assumed that dredged material was placed in a CDF, pore water seepage transported contaminants from the dredged material solids to foundation soils beneath the CDF, and that the dredged material was anaerobic. A detailed discussion of this assessment to include the theoretical basis for estimating contaminant pore water concentrations is presented in Appendix A.

259. Drinking water standards are not available for most organic contaminants. However, estimated pore water concentrations for organic contaminants were below available Federal drinking water standards. The estimated pore water concentrations for organic contaminants were also below acute fresh and marine water quality criteria (US Environmental Protection Agency 1986). Estimated pore water metal concentrations vary depending on distribution coefficients and percentage of the total metal concentration that is leachable. Based on equilibrium partitioning, estimated pore water concentrations in the dredged material for some metals could exceed drinking water standards, especially lead and chromium.

260. Estimates of pore water quality is just part of the information needed to evaluate leachate impacts on ground water resources. The hydraulic conductivity of the dredged material and foundation soils significantly affect seepage rate. The sorption properties of foundation soils also significantly affect the transport of contaminants to ground water. Most foundation soils can adsorb metals and attenuate their movement. In addition, dilution by groundwater and sorption by aquifer materials can lower contaminant concentrations at offsite monitoring wells to below drinking water limits. When seepage is low and soil sorption is high, impacts on groundwater can be negligible. Because of these considerations, it should be emphasized that estimates of pore water concentrations do not necessarily indicate that

groundwater leachate would be an environmental problem, only that additional tests would be warranted.

261. Based on this assessment, leach tests for lead and chromium would be needed for assessing groundwater impacts for specific permit applications in the future. The need for testing would depend on the groundwater resources at the CDF under consideration and the metals concentrations of sediments to be dredged.

Cost Estimates

262. A comparative cost estimate for hydraulic placement of materials from the three prospective dredging areas at each of the confined sites under consideration was prepared by the Norfolk District as shown in Table 23. These estimates were prepared using the same procedures as those used for preparing official estimates for bid purposes. However, all of the estimates were based on planning-level information and are therefore conservative. The estimates include mobilization/demobilization, direct dredging costs, and contingencies. Site preparation costs (e.g., site clearing, dike construction, and pipeline routing) were also included. These costs indicate placement of materials dredged from NWS Yorktown at the Forest and Magazine 13/14 sites to be slightly higher than a factor of two times the cost of disposal at Craney Island. Similarly, the placement of sediments from NAVPHIBASE LCREEK at the Rifle Range Pier 60, Landfill, or Beach Drive sites are comparable to the cost of disposal at Craney Island. The cost of transporting materials from NWS Yorktown and CAX to a NAVPHIBASE LCREEK CDF or vice versa would involve a long-distance haul by barge plus the cost of hydraulic offloading. The cost of these alternatives would be significantly higher than disposal at Craney Island, making these alternatives economically not practicable. However, the cost of placement of CAX materials at NWS Yorktown is exceptionally high, due to the small volume involved.

Assessment for Confined Disposal

Environmental assessment

263. Impacts to wetlands. The Lee Pond and Roosevelt Pond sites at NWS Yorktown, previously identified as potential confined sites in the Phase I study, were eliminated in Phase II because of potential impacts to wetlands.

No wetland areas have been identified near the Forest site at NWS Yorktown or the Rifle Range, Beach Drive, and Pier 60/New Magazine sites at NAVPHIBASE LCREEK. The Magazine 13/14 site at NWS Yorktown and the Landfill site at NAVPHIBASE LCREEK were configured to avoid suspected nearby wetland areas and freshwater springs. Their final configurations, if selected, must be determined considering the results of a site-specific wetlands delineation. Based on these considerations, the use of the Forest, Rifle Range, Magazine 13/14, Pier 60/New Magazine, Landfill, and Beach Drive sites may be practicable.

264. Contaminants. Results of the modified elutriate tests indicated that contaminant concentrations in the effluent were below Federal acute marine water quality criteria. Based on these considerations, use of the confined sites would be practicable from the standpoint of contaminant release in effluents during filling. Based on the results of column settling tests, the concentrations of suspended solids in CDF effluents would be well below the Norfolk District's self-imposed criterion of 5 g/ℓ. A conservative assessment of the potential for contaminant movement as leachate into groundwater indicated that additional leach tests may be needed for specific permit applications in the future.

Engineering assessment

265. The surface area of the available sites is limited to 5 to 8 acres. This presents a limitation of approximately 2.8 cfs for the maximum flow rate which the sites could accommodate during filling. The available sites would efficiently retain the suspended solids and result in an initial layer thickness of 3 to 4 ft of deposited dredged material.

266. The engineering criteria for confined disposal are concerned with the operational practicability of using hydraulic dredges or off-loading equipment to hydraulically fill the sites. Although the static head and pumping distances to the sites would reduce production/off-loading rates, no constraints in use of conventional equipment were identified. The limitation on maximum flow rate would indicate that hydraulic off-loading of barges would be more operationally practical than mobilization of a pipeline dredge for direct placement to the CDFs.

267. A site inspection and visual classification of site foundation soils indicated that dike construction should be practicable at any of the sites under consideration. However, an engineering design for dikes will be required for any site(s) finally selected. An assessment of the long-term

storage capacity needs for CDFs indicated that any site on NWS Yorktown and any site on NAVPHIBASE LCREEK property could meet the requirements for the respective facilities. Based on the above considerations, the use of any of the five CDF sites is practicable from an engineering standpoint.

Economic assessment

268. No specific economic criteria were used for confined disposal options for this study. Since the costs of confined options for placement of materials at CDFs were generally within a factor of two and were comparable with the cost of transporting the material to the Craney Island facility, these confined options were considered acceptable from the standpoint of cost. However, the higher cost of mechanically dredging material, transporting the material between facilities, and hydraulic offloading was considered economically not practicable; and no cost estimates were generated for those alternatives.

Practicability summary for confined disposal

269. Table 24 summarizes the practicability of confined disposal options with respect to environmental, engineering, and economic criteria. The Little Creek Cove site was determined to be not practicable due to conflicts with other land use planned by the Navy. The sites on NWS Yorktown property were considered not practicable for placement of NAVPHIBASE LCREEK material because of significantly higher cost. Similarly, sites on NAVPHIBASE LCREEK property were considered not practicable for placement of NWS Yorktown or CAX material. The Forest and Magazine 13/14 sites were considered practicable for placement of NWS Yorktown and CAX material with respect to all criteria. The Landfill and Beach Drive sites were not available for CDF construction pending resolution of Installation Restoration environmental issues. Only the Pier 60/New Magazine site is practicable for placement of NAVPHIBASE LCREEK material with respect to all criteria.

PART VI: ASSESSMENT OF BEACH NOURISHMENT AS A BENEFICIAL USE

Beach Nourishment as a Beneficial Use

270. While there are a variety of potential beneficial uses of dredged material, the use of acceptable material for beach nourishment/shoreline stabilization at NAVPHIBASE LCREEK and CAX was the only beneficial use identified in Phase I. Only coarse-grained sediment with low contaminant concentrations is usually considered for beach nourishment. The engineering criteria for acceptance of materials for beach nourishment are influenced by the material properties of the existing beach material. In general, medium sand or coarser material is desirable. The percent fines should not exceed 15 percent. Other factors such as the color of the sand are also considered. In general, "like-on-like" material is the desired result.

Potential sites for beach nourishment

271. Naval Weapons Station, Yorktown and Naval Supply Center, Cheatham Annex. The shoreline adjacent to Pier R-3 at the NWS Yorktown and the Supply and Fuel Piers at CAX were tentatively identified in Phase I as two potential sites for shoreline disposal of material dredged from nearby sites. The sediment characterization described in Part II indicated that sediments from NWS Yorktown and CAX are all fine-grained and contain concentrations of both metals and organic contaminants. Also, discussions with the Navy indicated that shoreline replenishment at Pier R-3 at NWS Yorktown would not be permitted due to the security requirements in this area. Based on these considerations, the use of sediments from NWS Yorktown and CAX for shoreline replenishment was not considered practicable.

272. Naval Amphibious Base Little Creek. Beaches to the east and west of the Little Creek Inlet jetties have been used for the disposal of material dredged from the main Little Creek Channel on two separate occasions. In 1975, all the material dredged from the main Little Creek Channel was placed on nearby beaches. Some of the material dredged from the channel contained silt and this resulted in several complaints regarding the quality of the beach sand. Therefore, when the Little Creek Channel was dredged in 1984, only select material from the channel fairway was used for disposal on nearby beaches.

Characterization of NAVPHIBASE LCREEK Beach Material

273. Samples of existing beach material were collected in September 1990 from beaches adjacent to the NAVPHIBASE LCREEK jetties. The grain size range of the material is shown in Figure 49. Comparison of this grain size distribution with that of the NAVPHIBASE LCREEK Channel as described in Part II shows that the existing beach sand falls within the range of the Channel sediments. However, the tributary sediments contain from 8 to 42 percent fine material. This confirms the past experience with beach nourishment at this site, which indicated that only about one third of the tributary sediment was acceptable for beach nourishment.

Assessment for Beach Nourishment

274. Table 25 summarizes the practicability assessment for beach nourishment. The sediment characterization for NAVPHIBASE LCREEK Channel indicated that a portion of the material meets the criteria for acceptability for beach nourishment. Based on this, the use of NAVPHIBASE LCREEK Channel sediments for beach nourishment is practicable. Grain size analysis is required to determine the portions of the Channel sediments acceptable for future specific permits.

PART VII: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

LTMS requirements

275. Based on the results of both the Phase I and Phase II studies, the following conclusions are made regarding requirements for the LTMS:

- a. Considering the locations of the prospective dredging areas and potential disposal sites, the geographic limits for the LTMS should encompass the lower York River and lower Chesapeake Bay. A 50-year disposal capacity was selected as the time frame for the LTMS.
- b. Based on historical dredging records for NWS Yorktown, CAX, and NAVPHIBASE LCREEK, the dredging requirements are 200,000 cu yd of material every 7 years at NWS Yorktown, 60,000 cu yd of material every 10 years at CAX, 140,000 cu yd of material every 4 years from the tributaries of NAVPHIBASE LCREEK, and 300,000 cu yd of material every 10 years from the main channel of NAVPHIBASE LCREEK.
- c. Over the 50-year life of this LTMS, the total dredging requirement which must be accommodated is approximately 4,880,000 cu yd. This exceeds the maximum total available volumetric capacity of 1,042,000 cu yd of all the prime candidate confined disposal sites. Therefore, placement of a significant fraction of the materials from these facilities at open-water disposal sites must be considered for the long term.
- d. Coordination is considered necessary to ensure that comments and concerns of the resource agencies and environmental groups are appropriately considered in the development of the LTMS. The regularly scheduled inter-agency meetings held by the CENAO prove to be a valuable forum for such coordination.

Screening criteria for practicability

276. The following conclusions are made regarding development of criteria for practicability of disposal options:

- a. Environmental criteria for open-water disposal options were developed within the framework of CWA Section 404, MPRSA Section 103, and the Corps management strategy. The main considerations in these assessments were the potential for physical impacts to sensitive resources, and the acceptability of materials for open-water disposal from the standpoint of contamination.
- b. Environmental criteria for confined disposal options included those concerned with potential impacts on wetlands and other sensitive resources and potential contaminant pathways for CDFs, primarily effluent discharge.

c. Screening criteria for beach nourishment were aimed at insuring that material was compatible with the existing beach material.

d. For all options, engineering criteria were concerned with design, construction, and operational practicability, and whether conventional equipment could be used under safe operating conditions.

e. No specific criteria for economic practicability were used for this study. However, cost estimates were made to compare the various options with the current costs of disposal at the Craney Island site.

Sediment characterization

277. The following conclusions are made regarding sediment characterization conducted for this study:

a. Conventional sampling techniques using a grab sampler proved adequate in collecting representative samples of sediments from the dredging areas.

b. Physical characterization tests indicated that sediments from NWS Yorktown and CAX were predominantly clays. Sediments from NAVPHIBASE LCREEK Tributaries were predominantly clays with some sand, while those from NAVPHIBASE LCREEK Channel were predominantly sand with some clay.

c. A sediment chemical inventory run for all the EPA priority pollutants detected metals in sediments from all three of the prospective dredging areas. Some stations contained PAHs and pesticides.

d. Because of the presence of contaminants in the sediments, additional environmental testing in accordance with MPRSA Section 103, CWA Section 404, and Corps Management Strategy was deemed appropriate.

e. Four composite samples were developed for additional environmental and engineering tests corresponding to four prospective dredging areas at NWS Yorktown, CAX, NAVPHIBASE LCREEK Tributaries, and NAVPHIBASE LCREEK Channel. The results of the composite testing are only considered appropriate for this LTMS in determining the overall suitability of material from a given dredging area for a given disposal option.

Open-water disposal options

278. The following conclusions were made regarding assessment of open-water disposal options:

a. Potential open-water disposal options include the Dam Neck, Norfolk, Thimble Shoal, Naval Channel, Wolf Trap Alternate, York River, and Rappahannock Shoal Alternate sites. Placement of materials from the four prospective dredging locations was considered for each of the seven sites, which resulted in 28 possible options for open-water placement.

b. Because all sites involve long haul distances, mechanical dredging and transport by barge is the most efficient method. It was assumed that mechanical dredging and filling of bottom-dump barges would be the dredging technique for all open-water disposal options.

c. Ocean and bay reference areas selected for this LTMS testing were considered representative of conditions adjacent to the sites under consideration, but not directly influenced by previous disposal. Different reference sites or reference areas may be more appropriate once specific open-water disposal alternatives and sites are selected.

d. The determination of suitability of the materials for open-water disposal involved laboratory tests for evaluating potential effects to the water column and benthos due to the presence of contaminants. This determination was made using a tiered approach involving both chemically based and biological tests and assessments.

e. No PAHs were detected in standard elutriate tests. Metals were detected, but were at concentrations below the Federal acute marine water quality criteria. Since the tests indicated no contaminant release above the criteria, all the materials are suitable for disposal at any of the open-water sites from the standpoint of water column contaminant effects.

f. Benthic toxicity tests indicated no significant differences between materials from the prospective dredging areas and either of the two reference sites in terms of *Neanthes* survival. On the basis of these results, all the materials are suitable for disposal at any of the open-water sites from the standpoint of benthic toxicity.

g. A TBP calculation indicated that no pesticides or PCBs were of concern from the standpoint of potential benthic bioaccumulation. However, the NAVPHIBASE LCREEK Tributary composite showed potential for bioaccumulation of PAHs, indicating that further bioaccumulation testing for PAHs was warranted. Subsequent benthic bioaccumulation tests indicated no significant bioaccumulation of PAHs in the NAVPHIBASE LCREEK Tributary sediments. All of the materials are considered suitable for disposal at any of the open-water sites from the standpoint of PAH bioaccumulation.

h. In all but one case, the organisms exposed to test sediments bioaccumulated less metal than organisms exposed to either of the reference sediments. In the single case where Pb was significantly bioaccumulated in NAVPHIBASE LCREEK Tributary sediment as compared to the Ocean reference sediment, the level of bioaccumulation shown by clams exposed to this sediment was more than an order of magnitude lower than a tissue level associated with any known toxic effects. Therefore, there is no reason to believe that the sediments are unsuitable for open-water disposal at any of the sites under consideration from the standpoint of bioaccumulation of contaminants.

i. Although testing indicated that sediments from all four prospective dredging areas are generally suitable for open-water disposal, it is possible that some of the material from these areas may be found to be unsuitable in the future. For purposes of this LTMS, it was assumed that 10 percent of the material from NWS Yorktown, CAX, and NAVPHIBASE LCREEK Tributaries would be unsuitable for open-water disposal in the future. The assumption of 10 percent was used to assess the acceptability of CDF sites from the standpoint of volumetric capacity and should ensure that adequate disposal capacity for potentially unsuitable material is provided.

j. A numerical model used to predict the short-term fate of dredged material at the open-water disposal sites indicated that the descent behavior was similar for all model runs at all sites and for all materials. The dredged material was predicted to descend to the bottom within a few seconds after discharge, and to accumulate on the bottom near the point of discharge. A small portion of the clay silt fraction was predicted to accumulate over a wider area around the point of discharge.

k. The water column plumes for the clay-silt fraction and fluid fraction were predicted to disperse over time with the plume centroid advected by the current. The maximum concentration of clay-silt in the plumes for all disposal sites and all dredged materials was generally below 100 mg/ℓ after initial mixing.

l. Sediment transport modeling was performed to determine if the disposal sites were either dispersive or accumulative. All seven of the potential open-water disposal sites would experience a minimal degree of disposal mound centroid movement under 48-hr northeaster storm events. The Norfolk, Naval Channel, and Rappahannock Shoal Alternate sites were found to be dispersive for both the NWS Yorktown and CAX dredged material. The Thimble Shoal site was found to be dispersive for materials from all four prospective dredging areas.

m. There are no commercial fisheries within 1 mile of any of the open-water disposal sites; all sites are deemed acceptable from the standpoint of potential physical impacts on sensitive resources.

n. Disposal operations have been successfully carried out at the open-water sites in the past using readily available equipment, and there is no indication that unusual safety considerations would apply. The volumes of material expected to be generated are quite small compared to the volumetric capacities of sites with established management plans. Therefore, use of any of the open-water sites for any of the materials is considered acceptable from an engineering practicability standpoint.

o. Since the costs for all open-water disposal options were generally comparable with the cost of transporting the material to the Craney Island facility, no open-water option was considered unacceptable from the standpoint of costs.

Confined disposal options

279. The following conclusions are made regarding the assessment of confined disposal options:

a. There is insufficient confined disposal capacity to meet the total dredging requirement, therefore CDF capacity should not be used for material that is suitable for other available alternatives.

b. It is assumed that 10 percent of the total volume of material from NWS Yorktown, CAX, and NAVPHIBASE LCREEK Tributaries may be found to be unsuitable for open-water disposal in the future. Several options can be considered for disposal of such unsuitable material to include capping or disposal in CDFs. However, CDFs have been used for disposal at these Naval facilities in the past, and CDFs were therefore assumed as the disposal option of choice for material unsuitable for open-water disposal if CDF capacity is available.

c. Potential CDF sites were evaluated on NWS Yorktown property and NAVPHIBASE LCREEK property. The Lee Pond, Roosevelt Pond, and Old Disposal sites, identified under Phase I, were eliminated because of potential impacts to wetlands. The remaining candidate sites were evaluated with respect to the surface area deemed practicable for dike construction. Two potential CDF sites on NWS Yorktown property are: Magazine 13/14 area (8 acres) and Forest area (7 acres). Three potential sites on NAVPHIBASE LCREEK property are: Pier 60/New Magazine area (6 acres), Landfill area (9 acres), and Beach Drive area (5 acres).

d. The CDF dikes were configured to avoid suspected nearby wetland areas and freshwater springs. The final configurations of these sites must be determined considering the results of site-specific wetlands delineations.

e. A site inspection and visual classification of site foundation soils indicated that dike construction should be practicable at any of the sites under consideration. However, an engineering design for dikes will be required for any site(s) finally selected.

f. The dredging at all sites will likely be done by clamshell dredges, with the sediments loaded into barges for open-water disposal. The likely method for placement of unsuitable material in CDFs will be hydraulic off-loading from barges. Direct placement to CDFs by pipeline dredge is a possibility, but would be inefficient considering the high mobilization costs, small volumes, limitations on flow rates, and dredging depths.

g. Although the static head and pumping distances to the sites would limit production/off-loading rates, no constraints in the use of conventional equipment were identified.

h. The design requirements for CDFs for retention of suspended solids and initial storage volume during filling were determined using the results of column settling tests and the surface areas available for diking. These tests indicated that the influent flow rate to CDFs should be limited to approximately 2.8 cfs (equivalent to an 8-in. pipeline at 8 ft/sec).

i. The surface area ponded at the beginning of dredging should be the total surface area diked. The average ponded depth at the end of pumping should be about 3 ft and should not vary greatly from place to place.

j. The shape of the CDF should be designed so that the hydraulic efficiency is at least 60 percent. This will probably require at least one spur dike.

k. The outlet weir should be designed to produce an average withdrawal depth of no greater than 2 ft. A length of at least 12 ft is recommended.

l. The lift thickness of sediment in a CDF of 5 acres following a filling cycle will be approximately 3-4 ft. The dikes should therefore be at least 8 ft to 10 ft high to accommodate the required 3-4 ft of sediment depth, 3 ft of ponded depth, and 2 ft of freeboard at the end of pumping.

m. The assessment of long-term storage capacity requirements indicated that any CDF site for NWS Yorktown/CAX and any site for NAVPHIBASE LCREEK would be adequate, assuming that 10 percent of the total dredging volume would be placed in CDFs. However, the Navy should reserve the development of both the Forest and Magazine 13/14 sites at NWS Yorktown in case the disposal requirements for unsuitable dredged material were to change in the future. Similarly, development of the Pier 60/New Magazine, Landfill, and Beach Drive sites should be reserved for CDF use at NAVPHIBASE LCREEK.

n. The CENAO self-imposed limit of 5 g/ℓ effluent suspended solids could be easily met by any of the CDFs if operated at the inflow rate of 2.8 cfs.

o. Results of modified elutriate tests indicated that contaminant concentrations in the effluent were below Federal acute marine criteria. Based on these considerations, use of the confined sites would be practicable from the standpoint of contaminant release in effluents during filling.

p. An assessment of the potential for movement of metals into groundwater beneath CDFs, based on conservative equilibrium partitioning principles, indicated that leach tests for lead and chromium may be needed for assessing groundwater impacts for specific permit applications in the future. The need for testing would depend on the groundwater resources at the CDF under consideration and the metals concentrations of sediments to be dredged.

q. The costs of placement of materials dredged from NWS Yorktown and CAX at the Forest and Magazine 13/14 sites are comparable with the cost of disposal at Craney Island. Similarly, the placement of sediments from NAVPHIBASE LCREEK at the Pier 60, Landfill, and Beach Drive sites are comparable with disposal at Craney Island. However, the cost of transporting materials from NWS Yorktown and CAX to NAVPHIBASE LCREEK CDFs, or vice versa, plus the cost of hydraulic offloading is significantly higher than disposal at Craney Island, making these alternatives economically not practicable.

r. During the review process for this report, environmental issues associated with Installation Restoration were investigated at the Landfill and Beach Drive sites at NAVPHIBASE LCREEK. These sites will not be available for CDF construction until these issues are resolved.

Beneficial use options

280. The following conclusions are made regarding the assessment of beach nourishment as a beneficial use option:

a. Beach nourishment at NAVPHIBASE LCREEK was identified as the only practicable beneficial use alternative. Since beneficial use is a preferred alternative, any material meeting the acceptability criteria for beach nourishment should be used for that purpose.

b. A sediment characterization for NAVPHIBASE LCREEK Channel indicated that approximately one-third of the material meets the criteria for acceptability for beach nourishment. Based on this, the use of NAVPHIBASE LCREEK Channel sediments for beach nourishment is deemed practicable. Grain size analysis is required to determine the acceptability of sediment from portions of the Channel for beach nourishment.

c. A sediment characterization for NWS Yorktown and CAX sediments indicated that the material is unsuitable for shoreline protection. Also, access to some shoreline areas is constrained by security requirements. Based on these considerations, shoreline protection at NWS Yorktown and CAX was considered not practicable.

Proposed Formulation of LTMS Alternatives for Phase III

281. The environmental, engineering, and economic practicability of open-water disposal, confined disposal, and beneficial uses was assessed in Phase II. These options were evaluated for all prospective dredging areas and all potential disposal sites. The options are grouped below into proposed LTMS alternatives for evaluation under Phase III which would meet the total long-term disposal requirement.

282. Obviously, there are numerous combinations of options. However, several considerations serve to focus the process of formulating alternatives:

a. There is insufficient confined disposal capacity to accommodate the total dredging requirement. Therefore, open-water disposal at in-bay or ocean sites will be an integral part of any alternative meeting the LTMS requirements.

b. Since beneficial uses is the preferred option for acceptable material, the use of this option will be an integral part of all alternatives.

c. Assuming that 10 percent of the total dredging requirement will be unsuitable for open-water disposal, the required confined capacity for all prospective dredging areas exceeds that available at either NWS Yorktown or NAVPHIBASE LCREEK sites. Also, the placement of material from one facility at CDFs on distant facilities was economically not practicable. Therefore, the LTMS must call for confined capacity at both locations.

d. It may be desirable to keep the number of bay sites to a minimum. Use of a single bay site for all of the Navy's requirement should be considered as an alternative.

e. It may be desirable to use only a presently active bay site for the Navy material.

f. Since the Norfolk ocean site is not yet designated, alternatives involving ocean disposal must specify that the Dam Neck site be used until the Norfolk site becomes available.

g. Although sediments from all the prospective dredging areas were found to be suitable for open-water disposal from the standpoint of contaminants, there is the possibility that sediments from future specific areas to be dredged will be unsuitable. Therefore, confined disposal capacity must be identified as a part of the LTMS.

283. Based on these considerations, a total of five LTMS alternatives were identified for consideration under Phase III as described below. All of the alternatives incorporated use of acceptable material from NAVPHIBASE LCREEK Channel for beach nourishment. Also, all alternatives incorporate use of confined sites at NWS Yorktown for unsuitable materials from NWS Yorktown and CAX and use of confined sites in NAVPHIBASE LCREEK for unsuitable materials from the Tributaries and Channel. The term "suitable" is defined in these descriptions as material determined to be suitable for open-water disposal at the site under consideration. The main difference among the alternatives is the number and location of open-water sites.

284. The five alternatives described below do not represent all possible combinations of options that could satisfy the criteria for technical practicability and do not consider practicability based on socio-economic, political, institutional, public interest, or other factors. Final formulation of LTMS alternatives must be accomplished in Phase III of the LTMS.

Alternative 1: Multiple bay sites/confined sites

285. This alternative involves use of multiple in-bay open-water sites for suitable material. Several in-bay sites are technically practicable for materials from each of the prospective dredging areas. This alternative was developed assuming that material from each of the areas would be taken to the closest practicable site. Alternative 1 consists of the following components:

- a. Suitable material from NWS Yorktown and CAX is placed at the York River site.
- b. Suitable material from the NAVPHIBASE LCREEK Tributaries and Channel (except that acceptable for beach nourishment) is placed at the Naval Channel site.
- c. Material from NAVPHIBASE LCREEK Channel acceptable for beach nourishment is used for nourishment of adjacent beaches.
- d. Unsuitable material from NWS Yorktown and CAX is placed at the Forest or Magazine 13/14 confined sites.
- e. Unsuitable material from NAVPHIBASE LCREEK Channel and Tributaries is placed at the Pier 60/New Magazine confined site.

Alternative 2: Single bay site/confined sites

286. This alternative involves use of a single in-bay open-water site for suitable material from all of the prospective dredging areas. The York River site identified for this option is practicable for placement of materials from all the prospective dredging areas and results in the shortest aggregate haul distance. Alternative 2 consists of the following components:

- a. Suitable material from NWS Yorktown, CAX, NAVPHIBASE LCREEK Tributaries and Channel (except that acceptable for beach nourishment) is placed at the York River site.
- b. Material from NAVPHIBASE LCREEK Channel acceptable for beach nourishment is used for nourishment of adjacent beaches.
- c. Unsuitable material from NWS Yorktown and CAX is placed at the Forest or Magazine 13/14 confined sites.
- d. Unsuitable material from NAVPHIBASE LCREEK Channel and Tributaries is placed at the Pier 60/New Magazine confined site.

Alternative 3: Single active bay site/confined sites

287. This alternative involves use of a single in-bay open-water site which is now actively being used for other projects. The Wolf Trap Alternate site is the logical choice for this alternative since the aggregate haul distance is much less than for the Rappahannock Shoal Alternate site. Alternative 3 consists of the following components:

- a. Suitable material from NWS Yorktown, CAX, NAVPHIBASE LCREEK Tributaries and Channel (except that acceptable for beach nourishment) is placed at the Wolf Trap Alternate site.

b. Material from NAVPHIBASE LCREEK Channel acceptable for beach nourishment is used for nourishment of adjacent beaches.

c. Unsuitable material from NWS Yorktown and CAX is placed at the Forest or Magazine 13/14 confined sites.

d. Unsuitable material from NAVPHIBASE LCREEK Channel and Tributaries is placed at the Pier 60/New Magazine confined site.

Alternative 4: Ocean sites/bay sites/confined sites

288. This alternative involves use of both ocean and in-bay open-water sites for suitable material. Sites were selected for this alternative assuming that material from NWS Yorktown and CAX would be taken to the closest practicable bay site, while suitable material from NAVPHIBASE LCREEK would be taken to the nearest approved ocean site. Alternative 4 consists of the following components:

a. Suitable material from NWS Yorktown and CAX is placed at the York River site.

b. Suitable material from the NAVPHIBASE LCREEK Tributaries and Channel (except that acceptable for beach nourishment) is placed at the Dam Neck ocean site until the Norfolk ocean site becomes available. Thereafter, the material would be placed at the Norfolk site.

c. Material from NAVPHIBASE LCREEK Channel acceptable for beach nourishment is used for nourishment of adjacent beaches.

d. Unsuitable material from NWS Yorktown and CAX is placed at the Forest or Magazine 13/14 confined sites.

e. Unsuitable material from NAVPHIBASE LCREEK Channel and Tributaries is placed at the Pier 60/New Magazine confined site.

Alternative 5: Ocean sites/confined sites

289. This alternative involves use of ocean sites for all suitable material. Alternative 5 consists of the following components:

a. Suitable material from NWS Yorktown, CAX, NAVPHIBASE LCREEK Tributaries and Channel (except that acceptable for beach nourishment) is placed at the Dam Neck ocean site until the Norfolk ocean site becomes available. Thereafter, the material would be placed at the Norfolk site.

b. Material from NAVPHIBASE LCREEK Channel acceptable for beach nourishment is used for nourishment of adjacent beaches.

c. Unsuitable material from NWS Yorktown and CAX is placed at the Forest or Magazine 13/14 confined sites.

d. Unsuitable material from NAVPHIBASE LCREEK Channel and Tributaries is placed at the Pier 60/New Magazine confined site.

Recommendations for Phase III

290. Phase III of the LTMS process involves the analysis of alternatives which meet the LTMS objectives and selection of a preferred alternative. Based on the results of the Phase I and Phase II studies, the following activities are recommended for Phase III:

a. Develop a final set of LTMS alternatives by combining the options for open-water disposal, confined disposal, and beach nourishment which meet the environmental, engineering, and economic criteria for technical practicability. The options must be grouped into LTMS alternatives which would meet the total long-term disposal need. Screen alternatives using technical criteria and additional criteria relating to institutional, political, public interest, and other factors.

b. Continue the coordination process with resource agencies regarding the results of the Phase I and Phase II studies and the formulation of LTMS alternatives.

c. Select a preferred LTMS alternative.

d. Pursue Section 103/404 permits for the selected LTMS alternative. This should be done concurrently with the NEPA process.

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Table 1

Summary of Feasibility Criteria

Disposal Option	Feasibility Criteria
Open Water	
Environmental	No commercial fisheries leases within 1 mile of disposal site.
	Site must be predominantly accumulative.
	Water column contaminant release less than Federal marine acute criteria after initial mixing (4-hr ocean, 1-hr bay).
	Benthic toxicity less than 10% above reference.
	No statistically significant bioaccumulation.
Engineering	Operationally feasible with respect to use of conventional equipment and safe operation.
Economic	Cost comparable to disposal at Craney Island.
Confined Disposal	
Environmental	No impacts to adjacent wetlands or sensitive resources.
	Design of CDFs using best management practices.
	Effluent suspended solids less than 5 g/ℓ.
Engineering	Operationally feasible with respect to use of conventional equipment and safe operation.
	Site conditions favorable to dike construction using conventional construction techniques.
	No interference with other planned land use by Navy.
Economic	Cost comparable to disposal at Craney Island.
Beneficial uses (Beach nourishment)	Material less than 15% fines and similar to existing material on the beach.

Table 2

Sediment Pysical Characteristics

Sample	USCS Class	t-Limits: Liquid Limit %	Plastic Limit %	Plasticity Index %	In Situ Water Content %	Organic Content %	Percent Passing #200 Sieve %
				NWS Yorktown			
NWS-10	(CH)	108	30	78	205.8	7.2	89
NWS-11	(CH)	130	41	89	217.8	7.8	98
NWS-12	(CH)	89	33	56	185.5	7.2	97
NWS-13	(CH)	127	38	89	227.2	8.2	98
NWS-14	(CH)	128	35	93	231.7	8.1	99
NWS-15	(CH)	109	36	73	176.5	7.0	97
NWS-16	(CH)	98	31	67	150.9	5.2	88
Avg.		113	35	78	199.3	7.2	95
				CAX			
CA-1	(CH)	122	40	82	183.9	8.3	97
CA-2	(CH)	124	39	85	218.1	6.6	98
CA-3	(CH)	115	35	80	169.1	6.5	99
CA-4	(CH)	104	34	70	244.4	7.2	97
CA-5	(CH)	128	42	86	175.2	8.0	98
CA-6	(CH)	103	31	72	154.4	6.8	93
Avg.		116	37	79	190.9	7.2	97
				NAVPHIBASE LCREEK TRIBUTARIES			
LC-1	(CH)	82	29	53	205.9	6.8	89
LC-2	(CH)	82	34	48	201.4	4.8	87
LC-3	(CH)	95	34	61	234.9	7.4	94
LC-5	(SC)	67	23	44	99.5	3.9	43
LC-6	(SC)	31	15	16	56.2	2.2	28
LC-8	(CH)	64	22	42	98.4	4.4	83
LC-9	(CH)	63	21	42	102.5	4.5	63
Avg.		69	25	44	142.7	4.9	70
				NAVPHIBASE LCREEK CHANNEL			
LC-4	(SC)	31	14	17	30.1	1.1	16
LC-7	(SM)	NP*	--	--	22.8	0.8	16
LC-10	(SM-SC)	25	19	6	48.9	2.4	34
LC-11	(SM)	NP	--	--	52.1	2.5	42
LC-12	(SP-SM)	NP	--	--	21.7	0.2	8
LC-13	(SM)	NP	--	--	32.6	1.26	32
LC-14	(SM)	NP	--	--	33.1	1.4	35
LC-15	(SM)	NP	--	--	30.8	1.3	23
Avg.		28	17	12	34.0	1.4	26

* NP - Non-plastic.

Table 3

Sediment Chemical Inventory for Navy LTMS, Detection Limits

Sample Station	Arsenic	Berillium	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Silver	Thallium	Zinc
	0.005	0.50	0.01	0.03	0.03	0.001	0.1	0.03	0.10	0.10	0.03
					NWS Yorktown						
NWS-10	4.90	1.00	0.12	53.6	27.1	16.8	--	29.0	0.10	0.40	131.0
NWS-11	3.90	1.00	0.13	57.2	28.4	18.6	--	32.3	0.40	0.20	141.0
NWS-12	4.80	1.10	0.10	58.9	31.7	19.6	--	30.5	0.10	0.30	137.0
NWS-13	4.30	1.10	0.27	58.4	29.2	19.3	--	31.8	0.10	0.30	142.0
NWS-14	3.10	1.00	0.15	56.9	27.3	21.2	--	29.4	0.10	0.30	141.0
NWS-15	4.90	1.00	--	55.3	28.1	22.4	--	29.7	0.10	0.20	136.0
NWS-16	3.50	0.90	0.12	51.4	24.3	19.9	--	26.0	0.10	0.40	119.0
Blank	0.005	--	--	--	--	--	--	--	--	--	--
					CAX						
CA-1	5.40	1.20	0.13	58.9	30.0	21.3	--	33.6	0.10	0.20	158.0
CA-2	5.50	1.20	--	56.0	27.2	19.1	--	29.8	0.10	0.20	146.0
CA-3	4.30	1.10	--	57.1	27.9	22.9	--	29.8	0.10	0.30	147.0
CA-4	5.10	1.20	--	57.4	28.5	18.8	--	30.9	0.20	0.30	145.0
CA-5	4.70	1.20	--	58.6	35.7	22.2	--	32.2	0.10	0.20	159.0
CA-6	4.00	1.10	--	49.2	20.8	21.4	--	27.4	0.10	0.30	113.0
Blank	0.005	--	--	--	--	--	--	--	--	--	--
					NAVPHIBASE LCREEK Tributaries						
LC-1	6.70	1.00	1.44	57.2	151.0	91.3	0.913	31.0	1.10	0.50	343.0
LC-2	6.49	0.90	0.20	53.9	102.0	78.9	0.143	28.8	0.30	0.40	252.0
LC-3	7.50	1.10	0.45	66.9	195.0	98.1	1.140	34.1	0.40	0.50	470.0
LC-5	4.60	--	--	37.1	110.0	67.1	0.799	22.9	0.20	0.30	231.0
LC-6	2.40	--	--	19.0	62.6	53.7	--	9.4	0.10	0.30	134.0
LC-8	5.00	0.70	--	41.6	28.4	51.1	0.182	21.7	0.10	0.30	102.0
LC-9	5.40	0.70	0.11	47.9	99.3	105.0	0.679	20.6	0.30	0.50	1010.0
					NAVPHIBASE LCREEK (Channel)						
LC-4	2.00	--	--	10.6	31.2	43.9	--	6.0	--	0.20	73.5
LC-7	1.20	--	--	7.1	10.9	20.3	--	3.9	--	0.10	32.4
LC-10	3.30	0.70	0.69	17.2	14.1	10.8	0.456	7.0	--	--	59.1
LC-11	5.10	0.80	0.52	17.4	11.5	13.8	0.243	8.5	--	--	53.2
LC-12	0.70	--	--	3.0	0.6	6.4	--	1.4	--	--	11.3
LC-13	1.90	--	--	14.6	5.3	12.8	--	9.1	--	--	44.5
LC-14	3.60	0.50	0.31	9.2	4.9	5.4	0.623	5.3	--	--	34.2
LC-15	3.10	0.50	0.35	10.1	5.0	9.1	0.459	5.4	--	--	36.6
Blank	--	--	--	--	--	0.011	--	1.0	--	--	--
YR-1	7.60	2.10	2.44	41.4	28.8	28.4	0.294	21.2	--	0.200	97.2
NC-1	3.60	0.80	0.20	13.0	2.8	4.8	0.610	5.1	--	--	25.9
TS-1	0.80	0.50	0.12	2.5	5.2	1.9	--	10.9	--	--	6.3
Blank	--	--	0.0004	--	0.001	0.001	--	0.003	--	--	--

(Continued)

Table 3 (Concluded)

Sample Station	Cyanide	D-BHC	PPDDD	PPDDE	PPDDT	HPTCL	DIELDRIN	ENDOSU	ENDRIN	ENDALD	HPTCLE	METOXYCL	FLANTHE	PYRENE	CHRYSE	B2EHPH	BBFLANT	PCB-1254	PCB-1260
	Variable		0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	Variable	Variable	Variable	Variable	Variable	0.002	0.002
NWS-10	--	--	0.0004	--	--	--	0.0009	--	--	--	--	--	--	--	--	--	--	--	--
NWS-11	--	--	--	0.0022	--	0.0038	--	--	--	--	0.0007	--	--	--	--	--	--	--	--
NWS-12	--	--	--	--	--	--	0.0005	--	0.0004	--	--	--	--	--	--	--	--	--	--
NWS-13	--	--	--	--	--	0.0006	--	--	0.0002	--	--	--	--	--	--	--	--	--	--
NWS-14	--	--	--	--	0.0015	--	--	0.0004	--	--	--	--	--	--	--	--	--	--	--
NWS-15	--	--	0.0004	--	0.0008	--	--	--	--	--	--	--	--	--	--	--	--	--	--
NWS-16	--	--	--	--	--	0.0012	--	0.0025	--	0.0011	--	0.0017	--	--	--	--	--	--	--
Blank	--	--	--	0.0003	--	0.0018	--	--	--	--	--	0.0017	--	--	--	--	--	--	--
CA-1	--	--	0.0013	0.0011	--	0.0013	--	--	--	--	--	--	--	--	--	--	--	--	--
CA-2	--	--	0.0012	0.0007	--	0.0039	--	--	--	--	--	--	1.200	--	--	--	--	--	--
CA-3	--	--	0.0008	--	--	0.0020	--	--	--	--	--	--	--	--	--	--	--	--	--
CA-4	--	--	0.0022	0.0019	0.0022	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CA-5	--	--	0.0048	--	--	0.0006	--	0.0012	--	--	--	--	--	--	--	--	--	--	--
CA-6	--	--	0.0050	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Blank	--	--	--	--	0.0022	--	--	--	--	--	--	--	--	--	--	--	--	--	--
LC-1	--	--	--	--	0.0057	0.0012	--	--	--	--	--	0.0053	--	--	--	--	--	--	0.070
LC-2	--	--	0.0029	0.0032	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
LC-3	--	--	0.0047	0.0059	--	--	--	--	--	--	--	--	1.100	1.700	--	--	--	--	--
LC-5	--	--	0.0060	--	--	--	0.0011	--	0.0020	--	--	--	1.500	1.800	--	--	--	--	--
LC-6	--	--	0.0034	0.0023	--	--	--	0.0005	--	--	--	--	0.520	1.100	0.940	--	0.78	--	--
LC-8	--	--	0.007	--	--	~~0.0010~~	--	~~0.0013~~	--	--	--	--	--	--	--	--	--	0.005	--
LC-9	0.873	--	--	0.0016	0.0030	0.0011	--	--	--	--	--	--	--	1.000	--	--	--	--	--
LC-4	--	--	--	0.0008	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
LC-7	--	--	0.0005	--	0.0010	--	--	--	--	--	--	--	--	--	--	0.530	--	--	--
LC-10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.004	--
LC-11	--	0.0009	0.0009	0.0005	--	--	--	0.0011	0.0005	--	--	--	--	--	--	--	--	--	--
LC-12	--	--	--	--	0.0010	0.0014	--	0.0003	--	--	--	--	--	--	--	--	--	--	--
LC-13	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
LC-14	--	--	--	--	--	--	--	0.0005	--	--	--	--	--	--	--	--	--	--	--
LC-15	--	--	--	--	--	0.0004	--	--	--	--	--	--	--	--	--	--	--	--	--
Blank	--	--	--	--	0.0017	0.0033	--	--	--	--	--	--	--	--	--	--	--	--	--
YR-1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.012	--
NC-1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TS-1	--	--	--	--	--	--	--	0.0002	--	--	--	--	--	--	--	--	--	0.002	--
Blank	--	--	--	--	--	0.0006	--	0.0003	--	--	--	--	--	--	--	--	--	0.004	--

Table 4

General Characteristics at Seven Proposed Dredged Material Disposal Sites

Disposal Site Location	Average Water Depth, ft	Typical Non-Storm Velocities, ft/sec	Average Velocity Direction	Well-Mixed Salinity ppt
Dam Neck	40	0.4	S	35
Norfolk	70	2.0	SSE	35
Thimble Shoal	22	2.1	SE	25
Naval Channel	35	1.7	SSE	25
Wolf Trap Alternative	38	1.5	S	22
York River	50	1.4	E	22
Rappahannock Alternative	40	1.8	S	18

Table 5

Standard Elutriate Concentrations in mg/ℓ

Sample Station	Arsenic	Chromium	Copper	Lead
NAVPHIBASE LCREEK Channel	*	0.024	*	0.005
NAVPHIBASE LCREEK Tributaries	0.036	*	0.008	0.009
CAX	0.036	*	*	0.005
NWS Yorktown	0.024	*	*	0.004
Federal Acute Marine Criteria	*	1.200	0.023	*

* Indicates concentration below detection limit.

Table 6

Percent Survival of *Neanthes Arenaceodentata* in a 10-Day Solid Phase Sediment Bioassay

Treatment	Percent Survival	S.D.	Replicates
NAVPHIBASE LCREEK 1	100.00	0.00	5
NAVPHIBASE LCREEK 2	90.00	12.25	5
NWS Yorktown	90.00	12.25	5
CAX	95.00	10.00	5
Ocean Reference	100.00	0.00	5
Bay Reference	95.00	10.00	5
Control	100.00	0.00	10

Table 7

Water Sample Chemical Concentrations in mg/ℓ

Sample Station	Arsenic	Cadmium	Chromium	Copper	Lead
Little Creek	0.032	0.0008	0.006	0.087	0.003
NWS	*	0.0012	0.003	0.011	0.002
CA	0.020	0.0024	*	0.007	0.005
YR	0.020	0.0016	0.003	0.002	0.003
NC	0.048	0.0036	*	0.002	0.003
TS	0.080	0.0016	*	0.006	0.003
Method Blank	*	*	*	*	*

Sample Station	Silver	Zinc	HPTCL	METOXYCL	PCB-1254
Little Creek	0.002	0.037	0.00001	*	*
NWS	0.001	*	*	0.00002	*
CA	*	*	*	*	*
YR	*	*	*	*	0.0002
NC	*	*	*	*	0.0002
TS	*	*	*	*	0.0006
Method Blank	*	*	*	*	0.0003

* Indicates concentration below detection limit.

Table 8

Statistical Comparison (t-tests) of Project Sediments with Ocean Reference (OR) and Bay Reference (BR) Materials

Comparison	Mean Difference	S.D.	T Value	P Value	
NAVIPHIBASE LCREEK 2 versus OR	10.00	13.69	1.633	0.178	NS*
NWS Yorktown versus OR	10.00	13.69	1.633	0.178	NS
CAX versus OR	5.00	11.18	1.000	0.374	NS
NAVPHIBASE LCREEK 2 versus BR	5.00	20.92	0.535	0.621	NS
NWS Yorktown versus BR	5.00	20.92	0.535	0.621	NS

* NS = Not statistically significant from reference.

Table 9

Sediment Chemical Inventory and Calculation of TBP* for Navy LTMS (Norfolk), Pesticides, Phthalates, and PCBs

Sediment Data**

Station	PPDDD	PPDDE	PPDDT	HPTCL	DIELDR	ENDOSU	ENDRIN	ENDALD	HPTCLE	METHOXY	B2EPH	PCB1254	PCB1260
NWS-10	0.0004	----	----	----	0.0009	----	----	----	----	----	----	----	----
NWS-11	----	0.0022	----	0.0038	----	----	----	----	0.0007	----	----	----	----
NWS-12	----	----	----	----	0.0005	----	0.0004	----	----	----	----	----	----
NWS-13	----	----	----	0.0006	----	----	0.0002	----	----	----	----	----	----
NWS-14	----	----	0.0015	----	----	0.0004	----	----	----	----	----	----	----
NWS-15	0.0004	----	0.0008	----	----	----	----	----	----	----	----	----	----
NWS-16	----	----	----	0.0012	----	0.0025	----	0.0011	----	0.0017	----	----	----
CA-1	0.0013	0.0011	----	0.0013	----	----	----	----	----	----	----	----	----
CA-2	0.0012	0.0007	----	0.0039	----	----	----	----	----	----	----	----	----
CA-3	0.0008	----	----	0.0020	----	----	----	----	----	----	----	----	----
CA-4	0.0022	0.0019	0.0022	----	----	----	----	----	----	----	----	----	----
CA-5	0.0048	----	----	0.0006	----	0.0012	----	----	----	----	----	----	----
CA-6	0.0050	----	----	----	----	----	----	----	----	----	----	----	----
LC-1	----	----	0.0057	0.0012	----	----	----	----	----	0.0053	----	----	0.0700
LC-2	0.0029	0.0032	----	----	----	----	----	----	----	----	----	----	----
LC-3	0.0047	0.0059	----	----	----	----	----	----	----	----	----	----	----
LC-4	----	0.0008	----	----	----	----	----	----	----	----	----	----	----
LC-5	0.0060	----	----	----	0.0011	----	0.0020	----	----	----	----	----	----
LC-6	0.0034	0.0023	----	----	----	0.0005	----	----	----	----	----	----	----
LC-7	0.0005	----	0.0010	----	----	----	----	----	----	----	0.5300	----	----
LC-8	0.0007	----	----	0.0010	----	0.0013	----	----	----	----	----	0.0050	----
LC-9	----	0.0016	0.0030	0.0011	----	----	----	----	----	----	----	----	----
LC-10	----	----	----	----	----	----	----	----	----	----	----	----	----
LC-11	----	----	----	----	----	----	----	----	----	----	----	----	----
LC-12	----	----	0.0010	0.0014	----	0.0003	----	----	----	----	----	----	----
LC-13	----	----	----	----	----	----	----	----	----	----	----	----	----
LC-14	----	----	----	----	----	----	----	----	----	----	----	----	----
LC-15	----	----	----	----	----	----	----	----	----	----	----	----	----

TBP for an Organism with 1% Lipid**

Station	PPDDD	PPDDE	PPDDT	HPTCL	DIELDR	ENDOSU	ENDRIN	ENDALD	HPTCLE	METHOXY	B2EPH	PCB1254	PCB1260
NWS-10	0.0016	----	----	----	0.0036	----	----	----	----	----	----	----	----
NWS-11	----	0.0089	----	0.0154	----	----	----	----	0.0028	----	----	----	----
NWS-12	----	----	----	----	0.0020	----	0.0016	----	----	----	----	----	----
NWS-13	----	----	----	0.0024	----	----	0.0008	----	----	----	----	----	----
NWS-14	----	----	0.0061	----	----	0.0016	----	----	----	----	----	----	----
NWS-15	0.0016	----	0.0032	----	----	----	----	----	----	----	----	----	----
NWS-16	----	----	----	0.0049	----	0.0101	----	0.0045	----	0.0069	----	----	----
CA-1	0.0034	0.0029	----	0.0034	----	----	----	----	----	----	----	----	----
CA-2	0.0031	0.0018	----	0.0101	----	----	----	----	----	----	----	----	----
CA-3	0.0021	----	----	0.0052	----	----	----	----	----	----	----	----	----
CA-4	0.0057	0.0049	0.0057	----	----	----	----	----	----	----	----	----	----
CA-5	0.0125	----	----	0.0016	----	0.0031	----	----	----	----	----	----	----
CA-6	0.0130	----	----	----	----	----	----	----	----	----	----	----	----

(Continued)

LC-1	----	----	0.0116	0.0024	----	----	----	----	----	0.0108	----	----	0.1420
LC-2	0.0059	0.0065	----	----	----	----	----	----	----	----	----	----	----
LC-3	0.0095	0.0120	----	----	----	----	----	----	----	----	----	----	----
LC-4	----	0.0024	----	----	----	----	----	----	----	----	----	----	----
LC-5	0.0122	----	----	----	0.0022	----	0.0041	----	----	----	----	----	----
LC-6	0.0069	0.0047	----	----	----	0.0010	----	----	----	----	----	----	----
LC-7	0.0015	----	0.0030	----	----	----	----	----	----	----	1.5704	----	----
LC-8	0.0014	----	----	0.0020	----	0.0026	----	----	----	----	----	0.0101	----
LC-9	----	0.0032	0.0061	0.0022	----	----	----	----	----	----	----	----	----
LC-10	----	----	----	----	----	----	----	----	----	----	----	----	----
LC-11	----	----	----	----	----	----	----	----	----	----	----	----	----
LC-12	----	----	0.0030	0.0041	----	0.0009	----	----	----	----	----	----	----
LC-13	----	----	----	----	----	----	----	----	----	----	----	----	----
LC-14	----	----	----	----	----	----	----	----	----	----	----	----	----
LC-15	----	----	----	----	----	----	----	----	----	----	----	----	----

TBP for an Organism with 3% Lipid**

Station	PPDDD	PPDDE	PPDDT	HPTCL	DIELDR	ENDOSU	ENDRIN	ENDALD	HPTCLE	METHOXY	B2EPH	PCB1254	PCB1260
NWS-10	0.0049	----	----	----	0.0109	----	----	----	----	----	----	----	----
NWS-11	----	0.0267	----	0.0462	----	----	----	----	0.0085	----	----	----	----
NWS-12	----	----	----	----	0.0061	----	0.0049	----	----	----	----	----	----
NWS-13	----	----	----	0.0073	----	----	0.0024	----	----	----	----	----	----
NWS-14	----	----	0.0182	----	----	0.0049	----	----	----	----	----	----	----
NWS-15	0.0049	----	0.0097	----	----	----	----	----	----	----	----	----	----
NWS-16	----	----	----	0.0146	----	0.0304	----	0.0134	----	0.0206	----	----	----
CA-1	0.0101	0.0086	----	0.0101	----	----	----	----	----	----	----	----	----
CA-2	0.0093	0.0054	----	0.0304	----	----	----	----	----	----	----	----	----
CA-3	0.0062	----	----	0.0156	----	----	----	----	----	----	----	----	----
CA-4	0.0171	0.0148	0.0171	----	----	----	----	----	----	----	----	----	----
CA-5	0.0374	----	----	0.0047	----	0.0093	----	----	----	----	----	----	----
CA-6	0.0389	----	----	----	----	----	----	----	----	----	----	----	----
LC-1	----	----	0.0347	0.0073	----	----	----	----	----	0.0323	----	----	0.4260
LC-2	0.0176	0.0195	----	----	----	----	----	----	----	----	----	----	----
LC-3	0.0286	0.0359	----	----	----	----	----	----	----	----	----	----	----
LC-4	----	0.0071	----	----	----	----	----	----	----	----	----	----	----
LC-5	0.0365	----	----	----	0.0067	----	0.0122	----	----	----	----	----	----
LC-6	0.0207	0.0140	----	----	----	0.0030	----	----	----	----	----	----	----
LC-7	0.0044	----	0.0089	----	----	----	----	----	----	----	4.7111	----	----
LC-8	0.0043	----	----	0.0061	----	0.0079	----	----	----	----	----	0.0304	----
LC-9	----	0.0097	----	0.0067	----	----	----	----	----	----	----	----	----
LC-10	----	----	----	----	----	----	----	----	----	----	----	----	----
LC-11	----	----	----	----	----	----	----	----	----	----	----	----	----
LC-12	----	----	0.0089	0.0124	----	0.0027	----	----	----	----	----	----	----
LC-13	----	----	----	----	----	----	----	----	----	----	----	----	----
LC-14	----	----	----	----	----	----	----	----	----	----	----	----	----
LC-15	----	----	----	----	----	----	----	----	----	----	----	----	----

(Continued)

Table 9 (Concluded)

	TBP for an Organism with 6% Lipid**												
Station	PPDDD	PPDDE	PPDDT	HPTCL	DIELDR	ENDOSU	ENDRIN	ENDALD	HPTCLE	METHOXY	B2EPH	PCB1254	PCB1260
NWS-10	0.0097	----	----	----	0.0219	----	----	----	----	----	----	----	----
NWS-11	----	0.0534	----	0.0923	----	----	----	----	0.0170	----	----	----	----
NWS-12	----	----	----	----	0.0121	----	0.0097	----	----	----	----	----	----
NWS-13	----	----	----	0.0146	----	----	0.0049	----	----	----	----	----	----
NWS-14	----	----	0.0364	----	----	0.0097	----	----	----	----	----	----	----
NWS-15	0.0097	----	0.0194	----	----	----	----	----	----	----	----	----	----
NWS-16	----	----	----	0.0291	----	0.0607	----	0.0267	----	0.0413	----	----	----
CA-1	0.0202	0.0171	----	0.0202	----	----	----	----	----	----	----	----	----
CA-2	0.0187	0.0109	----	0.0607	----	----	----	----	----	----	----	----	----
CA-3	0.0125	----	----	0.0311	----	----	----	----	----	----	----	----	----
CA-4	0.0342	0.0296	0.0342	----	----	----	----	----	----	----	----	----	----
CA-5	0.0747	----	----	0.0093	----	0.0187	----	----	----	----	----	----	----
CA-6	0.0778	----	----	----	----	----	----	----	----	----	----	----	----
LC-1	----	----	0.0694	0.0146	----	----	----	----	----	0.0645	----	----	0.8519
LC-2	0.0353	0.0389	----	----	----	----	----	----	----	----	----	----	----
LC-3	0.0572	0.0718	----	----	----	----	----	----	----	----	----	----	----
LC-4	----	0.0142	----	----	----	----	----	----	----	----	----	----	----
LC-5	0.0730	----	----	----	0.0134	----	0.0243	----	----	----	----	----	----
LC-6	0.0414	0.0280	----	----	----	0.0061	----	----	----	----	----	----	----
LC-7	0.0089	----	0.0178	----	----	----	----	----	----	----	9.4222	----	----
LC-8	0.0085	----	----	0.0122	----	0.0158	----	----	----	----	----	0.0609	----
LC-9	----	0.0195	0.0365	0.0134	----	----	----	----	----	----	----	----	----
LC-10	----	----	----	----	----	----	----	----	----	----	----	----	----
LC-11	----	----	----	----	----	----	----	----	----	----	----	----	----
LC-12	----	----	0.0178	0.0249	----	0.0053	----	----	----	----	----	----	----
LC-13	----	----	----	----	----	----	----	----	----	----	----	----	----
LC-14	----	----	----	----	----	----	----	----	----	----	----	----	----
LC-15	----	----	----	----	----	----	----	----	----	----	----	----	----

* TBP = 4 x (Sediment Contaminant Concentration/TOC) x Organism Lipid Fraction

** PPDDD = p,p'-DDD; PPDDE = p,p'-DDE; PPDDT = p,p'-DDT; HPTCL = Heptachlor; DIELDR = Dieldrin; ENDOSU = Endosulfan; ENDRIN = Endrin; ENDALD = Endrin aldehyde; HPTCLE = Heptachlor epoxide; METHOXY = Methoxychlor; B2EPH = Bis-2-ethyl hexyl phthalate; PCB1254 = Aroclor 1254; PCB1260 = Aroclor 1260

Table 10

Sediment Chemical Inventory and Calculation of TBP*

for Navy LTMS (Norfolk), PAHs

Station	Sediment Data**				TBP for an Organism with 1% Lipid**			
	FLUORAN	PYRENE	CHRYSE	BBFLUOR	FLUORAN	PYRENE	CHRYSE	BBFLUOR
NWS-10	--	--	--	--	--	--	--	--
NWS-11	--	--	--	--	--	--	--	--
NWS-12	--	--	--	--	--	--	--	--
NWS-13	--	--	--	--	--	--	--	--
NWS-14	--	--	--	--	--	--	--	--
NWS-15	--	--	--	--	--	--	--	--
NWS-16	--	--	--	--	--	--	--	--
CA-1	--	--	--	--	--	--	--	--
CA-2	1.2000	--	--	--	3.1128	--	--	--
CA-3	--	--	--	--	--	--	--	--
CA-4	--	--	--	--	--	--	--	--
CA-5	--	--	--	--	--	--	--	--
CA-6	--	--	--	--	--	--	--	--
LC-1	--	--	--	--	--	--	--	--
LC-2	--	--	--	--	--	--	--	--
LC-3	1.1000	1.7000	--	--	2.2312	3.4483	--	--
LC-4	--	--	--	--	--	--	--	--
LC-5	1.5000	1.8000	--	--	3.0426	3.6511	--	--
LC-6	0.5200	1.1000	0.9400	0.7800	1.0548	2.2312	1.9067	1.5822
LC-7	--	--	--	--	--	--	--	--
LC-8	--	--	--	--	--	--	--	--
LC-9	--	1.0000	--	--	--	2.0284	--	--
LC-10	--	--	--	--	--	--	--	--
LC-11	--	--	--	--	--	--	--	--
LC-12	--	--	--	--	--	--	--	--
LC-13	--	--	--	--	--	--	--	--
LC-14	--	--	--	--	--	--	--	--
LC-15	--	--	--	--	--	--	--	--

(Continued)

* TBP = 4 × (sediment contaminant concentration/TOC) × organism lipid fraction.

** FLUORAN = fluoranthene; PYRENE = pyrene; CHRYSE = chrysene; BBFLUOR = benzo[b]fluoranthene.

Table 10 (Concluded)

	TBP for an Organism with 3% Lipid**				TBP for an Organism with 6% Lipid**			
Station	FLUORAN	PYRENE	CHRYSE	BBFLUOR	FLUORAN	PYRENE	CHRYSE	BBFLUOR
NWS-10	--	--	--	--	--	--	--	--
NWS-11	--	--	--	--	--	--	--	--
NWS-12	--	--	--	--	--	--	--	--
NWS-13	--	--	--	--	--	--	--	--
NWS-14	--	--	--	--	--	--	--	--
NWS-15	--	--	--	--	--	--	--	--
NWS-16	--	--	--	--	--	--	--	--
CA-1	--	--	--	--	--	--	--	--
CA-2	9.3385	--	--	--	18.6770	--	--	--
CA-3	--	--	--	--	--	--	--	--
CA-4	--	--	--	--	--	--	--	--
CA-5	--	--	--	--	--	--	--	--
CA-6	--	--	--	--	--	--	--	--
LC-1	--	--	--	--	--	--	--	--
LC-2	--	--	--	--	--	--	--	--
LC-3	6.6937	10.3448	--	--	13.3874	20.6897	--	--
LC-4	--	--	--	--	--	--	--	--
LC-5	9.1278	10.9533	--	--	18.2556	21.9067	--	--
LC-6	3.1643	6.6937	5.7201	4.7465	6.3286	13.3874	11.4402	9.4929
LC-7	--	--	--	--	--	--	--	--
LC-8	--	--	--	--	--	--	--	--
LC-9	--	6.0852	--	--	--	12.1704	--	--
LC-10	--	--	--	--	--	--	--	--
LC-11	--	--	--	--	--	--	--	--
LC-12	--	--	--	--	--	--	--	--
LC-13	--	--	--	--	--	--	--	--
LC-14	--	--	--	--	--	--	--	--
LC-15	--	--	--	--	--	--	--	--

* TBP = 4 × (sediment contaminant concentration/TOC) × organism lipid fraction.

** FLUORAN = fluoranthene; PYRENE = pyrene; CHRYSE = chrysene; BBFLUOR = benzo[b]fluoranthene.

Table 11

Metal Residues in Clams Exposed to Test and Reference Sediments

Sediment	Analyte mg/kg*						
	Cd	Cr	Cu	Pb	Hg	Ni	Zn
NWS Yorktown	.055	.819	3.35	.426	.029	.413	26.7
CAX	.064	.656	2.93	.431	.026	.424	28.4
NAVPHIBASE LCREEK Channel	.066	.588	3.17	.410	.032	.383	31.7
NAVPHIBASE LCREEK Tributaries	.074	.793	4.56	.606**	.038†	.440	32.7
Bay Reference	.104	.825	4.87	.734	.035	.523	33.2
Ocean Reference	.089	.842	4.93	.495	.035	.466	40.3

* The value given is the mean of three experimental replicates.
** Bioaccumulation value is greater than that for clams exposed to ocean reference sediments.
† Although the bioaccumulation value is greater than that for clams exposed to ocean reference sediments or bay reference sediments, the difference is not statistically (*t*-test) different.

Table 12

Statistical Comparison of Bioaccumulation Values From the Test Sites With Reference Sites

Analyte	Test Site*	Reference Site**	P≤†
Cd	.0647	.0965	.05
Cr	.7140	.8335	NS
Cu	3.5033	4.9000	NS
Pb	.4540	.6145	.05
Hg	.0313	.0350	NS
Ni	.4150	.4945	.01
Zn	29.8750	36.7800	NS

* The mean of all the test site bioaccumulation values.

** The mean of all the reference site bioaccumulation values.

† In every case the mean bioaccumulation value for all test sites was lower than the mean bioaccumulation value for the reference sites. A paired, one-tailed *t*-test was performed to examine the significance of this difference between the means. This column gives the result of that test. The differences were either NS (not significantly different) or significantly lower at the *P* level given in this column.

Table 13

Maximum Observed Plume Concentrations of Clay-Silt in mg/ℓ

Maximum Concentrations Over Entire Grid After Initial Mixing, mg/ℓ

Site	NWS Yorktown/CAX	NAVPHIBASE LCREEK Tributaries
Dam Neck	1	1
Norfolk	<1	<1
Thimble Shoal	38	33
Naval Channel	201	188
York River	59	60
Wolf Trap Alternate	70	65
Rappahannock Shoal Alternate	79	42

Maximum Concentrations Outside Site Boundary at Any Time, mg/ℓ

Site	NWS Yorktown/CAX	NAVPHIBASE LCREEK Tributaries
Dam Neck	3	3
Norfolk	2	2
Thimble Shoal	97	83
Naval Channel	1,138	106
York River	53	290
Wolf Trap Alternate	7	6
Rappahannock Shoal Alternate	65	57

Table 14

Maximum Observed Plume Concentrations of Fluid Phase, Percent

Maximum Concentrations Over Entire Grid After Initial Mixing, Percent

Site	NWS Yorktown/CAX	NAVPHIBASE LCREEK Tributaries
Dam Neck	<.001	<.001
Norfolk	<.001	<.001
Thimble Shoal	.056	.056
Naval Channel	.061	.061
York River	.031	.031
Wolf Trap Alternate	.030	.030
Rappahannock Shoal Alternate	.029	.030

Maximum Concentrations Outside Site Boundary at Any Time, Percent

Site	NWS Yorktown/CAX	NAVPHIBASE LCREEK Tributaries
Dam Neck	<.001	<.001
Norfolk	.0013	.0013
Thimble Shoal	.129	.130
Naval Channel	.313	.313
York River	.137	.143
Wolf Trap Alternate	.0036	.0035
Rappahannock Shoal Alternate	.024	.0023

Table 15

Grain Sizes and Volumes of Dredged Materials

Location	Actual Grain Size, D_{50}, mm	Simulation Grain Size, D_{50}, mm	Volume to be Dredged cu yd/50 years
CAX	0.006	0.0625	300,000
NWS Yorktown	0.008	0.0625	1,400,000
NAVPHIBASE LCREEK (Tributaries)	0.140	0.1400	1,680,000
NAVPHIBASE LCREEK (Channel)	0.200	0.2000	1,500,000
TOTAL			4,880,000

Table 16

Areas and Hydrodynamic Characteristics of Seven Proposed Dredged Material Disposal Sites

			Average Long-Term		
Location	Tentative Disposal Site Area, sq mi	Computational Disposal Site Area, sq mi	Tide Amplitude, ft	Tidal Velocity Amplitude, ft/sec	Residual Velocity, ft/sec
Norfolk	65.0	1.0	1.7	2.0	0.20
Dam Neck	10.0	1.0	1.7	0.4	0.20
Thimble Shoal	1.0	1.0	1.3	2.1	0.20
Naval Channel	1.4	1.0	1.3	1.7	0.20
York River	1.0	1.0	1.3	1.4	0.15
Wolf Trap	8.0	1.0	0.8	1.5	0.15
Rappahannock	5.0	1.0	0.6	1.8	0.15

Table 17

Relative Movement of Disposal Mound Centroids by Analogous Hydrodynamic Forces, Seven Potential Disposal Sites With Four Disposed Materials Each

Disposal Site/Dredged Material	Centroid Movement After 3-Month Long-term Simulation, ft	Centroid Movement After 48-hr Northeaster Storm Simulation, ft
Norfolk/NWS Yorktown	1,350	174
Norfolk/CAX	1,350	174
Norfolk/NAVPHIBASE LCREEK Tributaries	99	99
Norfolk/NAVPHIBASE LCREEK Channel	64	41
Dam Neck/NWS Yorktown	0	388
Dam Neck/CAX	0	388
Dam Neck/NAVPHIBASE LCREEK Tributaries	0	43
Dam Neck/NAVPHIBASE LCREEK Channel	0	25
Thimble Shoal/NWS Yorktown	*	*
Thimble Shoal/CAX	*	*
Thimble Shoal/NAVPHIBASE LCREEK Tributaries	1,626	366
Thimble Shoal/NAVPHIBASE LCREEK Channel	724	334
Naval Channel/NWS Yorktown	2,974	228
Naval Channel/CAX	2,975	228
Naval Channel/NAVPHIBASE LCREEK Tributaries	189	208
Naval Channel/NAVPHIBASE LCREEK Channel	110	98
York River/NWS Yorktown	43	113
York River/CAX	43	113
York River/NAVPHIBASE LCREEK Tributaries	9	59
York River/NAVPHIBASE LCREEK Channel	7	27
Wolftrap/NWS Yorktown	272	235
Wolftrap/CAX	272	235
Wolftrap/NAVPHIBASE LCREEK Tributaries	32	125
Wolftrap/NAVPHIBASE LCREEK Channel	24	52
Rappahannock/NWS Yorktown	1,494	218
Rappahannock/CAX	1,494	218
Rappahannock/NAVPHIBASE LCREEK Tributaries	93	162
Rappahannock/NAVPHIBASE LCREEK Channel	59	70

* The hydrodynamic and sedimentary conditions for these scenarios are beyond the range of applicability of the numerical simulation model.

Table 18

Relative Dispersiveness of Four Dredged Materials Placed at Seven Potential Disposal Sites

Disposal Site/Dredged Material	Dispersive	Moderately Dispersive	Non-Dispersive
Norfolk/NWS Yorktown	X		
Norfolk/CAX	X		
Norfolk/NAVPHIBASE LCREEK Tributaries			X
Norfolk/NAVPHIBASE LCREEK Channel			X
Dam Neck/NWS Yorktown			X
Dam Neck/CAX			X
Dam Neck/NAVPHIBASE LCREEK Tributaries			X
Dam Neck/NAVPHIBASE LCREEK Channel			X
Thimble Shoal/NWS Yorktown	X		
Thimble Shoal/CAX	X		
Thimble Shoal/NAVPHIBASE LCREEK Tributaries	X		
Thimble Shoal/NAVPHIBASE LCREEK Channel	X		
Naval Channel/NWS Yorktown	X		
Naval Channel/CAX	X		
Naval Channel/NAVPHIBASE LCREEK Tributaries		X	
Naval Channel/NAVPHIBASE LCREEK Channel		X	
York River/NWS Yorktown			X
York River/CAX			X
York River/NAVPHIBASE LCREEK Tributaries			X
York River/NAVPHIBASE LCREEK Channel			X
Wolftrap/NWS Yorktown		X	
Wolftrap/CAX		X	
Wolftrap/NAVPHIBASE LCREEK Tributaries			X
Wolftrap/NAVPHIBASE LCREEK Channel			X
Rappahannock/NWS Yorktown	X		
Rappahannock/CAX	X		
Rappahannock/NAVPHIBASE LCREEK Tributaries			X
Rappahannock/NAVPHIBASE LCREEK Channel			X

Table 19

Estimated Dredging Costs for Open-Water Disposal Options*

Project Name	Rapp Shoal Alt	Wolf Trap Alt	Naval Channel Site	Thimble Shoal Site	York River Site	Dam Neck Site	Norfolk Ocean Site	Craney Island Site
NWS	$2,345*	$1,945	$1,945	$1,945	$1,245	$2,345	$3,345	$3,364
Yorktown	(48 mi)**	(26 mi)	(20 mi)	(28 mi)	(6 mi)	(47 mi)	(60 mi)	(54 mi)
(200,000 CY)	11.72***	9.72	9.72	9.72	6.22	11.72	16.72	16.82
CAX	$563	$473	$473	$473	$383	$563	$623	$647
	(56 mi)	(34 mi)	(28 mi)	(36 mi)	(14 mi)	(55 mi)	(68 mi)	(58 mi)
(30,000 CY)	18.76	15.76	15.76	15.76	12.76	18.76	20.76	21.57
NAVPHIBASE	$2,103	$1,683	$1,263	$1,263	$1,683	$1,263	$1,683	$1,592
LCREEK	(56 mi)	(33 mi)	(17 mi)	(11 mi)	(41 mi)	(23 mi)	(40 mi)	(16 mi)
Channel	15.02	12.02	9.02	9.02	12.02	9.02	12.02	11.37
(140,000 CY)								
NAVPHIBASE	$4,343	$3,443	$2,543	$2,543	$3,443	$2,543	$3,443	$3,246
LCREEK	(58 mi)	(35 mi)	(19 mi)	(13 mi)	(43 mi)	(25 mi)	(42 mi)	(16 mi)
Tributaries	14.47	11.47	8.47	8.47	11.47	8.47	11.47	10.82
(300,000 CY)								

* First entry is total estimated cost in $1,000; second entry is haul distance, miles; third entry is unit cost, $/cubic yard.

Table 20

Feasibility Summary for Open-Water Disposal Options*

Site/Criteria	Dredged Material NWS	CAX	NAVPHIBASE LCREEK Tributaries	NAVPHIBASE LCREEK Channel
Dam Neck				
Environmental				
Water column toxicity	+	+	+	+
Benthic toxicity	+	+	+	+
Bioaccumulation	+	+	+	+
Engineering	+	+	+	+
Economic	+	+	+	+
Overall Feasibility	P	P	P	P
Norfolk				
Environmental				
Water column toxicity	+	+	+	+
Benthic toxicity	+	+	+	+
Bioaccumulation	+	+	+	+
Engineering	+	+	+	+
Economic	+	+	+	+
Overall Feasibility	P	P	P	P
Thimble Shoal				
Environmental				
Water column toxicity	+	+	+	+
Benthic toxicity	+	+	+	+
Bioaccumulation	+	+	+	+
Physical impacts	+	+	+	+
Mound stability	-	-	-	-
Engineering	+	+	+	+
Economic	+	+	+	+
Overall Feasibility	N	N	N	N

(Continued)

* + indicates the site is practicable as determined by criterion.
- indicates the site is not practicable as determined by criterion.
P indicates the option is practicable overall considering all criteria.
N indicates the option is not practicable overall considering all criteria.
It should be noted that the designation of practicable does not indicate that the use of a particular site for a specific future dredging project would be acceptable. Acceptability of disposal of a specific material at a specific site would still require a permit evaluation with appropriate testing and assessments.

Table 20 (Concluded)

Site/Criteria	Dredged Material NWS	CAX	NAVPHIBASE LCREEK Tributaries	NAVPHIBASE LCREEK Channel
Naval Channel				
Environmental				
Water column toxicity	+	+	+	+
Benthic toxicity	+	+	+	+
Bioaccumulation	+	+	+	+
Physical impacts	+	+	+	+
Mound stability	-	-	+	+
Engineering	+	+	+	+
Economic	+	+	+	+
Overall Feasibility	N	N	P	P
York River				
Environmental				
Water column toxicity	+	+	+	+
Benthic toxicity	+	+	+	+
Bioaccumulation	+	+	+	+
Physical impacts	+	+	+	+
Engineering	+	+	+	+
Economic	+	+	+	+
Overall Feasibility	P	P	P	P
Wolf Trap Alternate				
Environmental				
Water column toxicity	+	+	+	+
Benthic toxicity	+	+	+	+
Bioaccumulation	+	+	+	+
Physical impacts	+	+	+	+
Mound stability	+	+	+	+
Engineering	+	+	+	+
Economic	+	+	+	+
Overall Feasibility	P	P	P	P
Rappahannock Shoal Alternate				
Environmental				
Water column toxicity	+	+	+	+
Benthic toxicity	+	+	+	+
Bioaccumulation	+	+	+	+
Physical impacts	+	+	+	+
Mound stability	-	-	+	+
Engineering	+	+	+	+
Economic	+	+	+	+
Overall Feasibility	N	N	P	P

Table 21

Summary of Information on Possible Disposal Sites

	Site				
	NWS Yorktown		NAVPHIBASE LCREEK		
Parameter	Magazine 13/14	Forest	Pier 60/ New Magazine	Landfill	Beach Drive
Pumping distance, mi	4.2	1.5-3	0.1	0.2	0.4
Static head, ft	50/60	40	15	18	10
Total area, acres	27	18	10	14	20
Maximum ponding area, acres	8/5	7	6	9	5
Ponding Depth, ft	0-40/2-5	2-5	2-5	2-5	2-5

Table 22

Modified Elutriate Concentrations in mg/ℓ

Sample Station	Arsenic	Cadmium	Chromium	Copper	Lead	Silver	Zinc
NAVPHIBASE LCREEK Channel	*	0.0001	*	*	0.004	*	*
NAVPHIBASE LCREEK Tributaries	0.016	0.0004	0.006	0.020	0.007	0.002	0.016
CAX	0.028	0.0001	*	0.006	0.004	*	*
NWS Yorktown	0.020	*	0.009	*	0.005	*	*
Federal Acute Marine Criteria	*	0.0590	1.260	0.023	*	*	0.170

* Indicates concentration below detection limit.

Table 23

Estimated Dredging Cost for Confined Disposal Options*

Name	Little Creek Sites: MAG/Pier 60	Little Creek Sites: Beach Site	Little Creek Sites: Landfill Site	York River Sites: MAG 13/14 Site	York River Sites: Forest Site
NWS Yorktown (20,000 CY)				$940 $47	$800 $40
CAX (3,000 CY)				$795 $265	$735 $245
NAVPHIBASE LCREEK Tributaries (30,000 CY)	$514 $17	$603 $20.01	$603 $20.01		

* Costs include construction of confined disposal areas. First entry is total estimated cost in $1,000. Second entry is unit cost in $/cubic yard.

Table 24

Feasibility Summary for Confined Disposal Options*

Site/Criteria	Dredged Material: NWS	CAX	NAVPHIBASE LCREEK Tributaries	NAVPHIBASE LCREEK Channel
NWS Yorktown Magazine 13/14				
Environmental				
Impacts to wetlands	+	+	+	+
Effluent quality	+	+	+	+
Engineering				
Operational suitability	+	+	+	+
Ponded area	+	+	+	+
Total volume	+	+	+	+
Dike construction	+	+	+	+
Land use compatibility	+	+	+	+
Economic	+	+	-	-
Overall Feasibility	P	P	N	N
NWS Yorktown Forest				
Environmental				
Impacts to wetlands	+	+	+	+
Effluent quality	+	+	+	+
Engineering				
Operational suitability	+	+	+	+
Ponded area	+	+	+	+
Total volume	+	+	+	+
Dike construction	+	+	+	+
Land use compatibility	+	+	+	+
Economic	+	+	-	-
Overall Feasibility	P	P	N	N
NAVPHIBASE LCREEK Desert				
Little Creek Cove				
Engineering				
Land use compatibility	-	-	-	-
Overall Feasibility	N	N	N	N

(Continued)

* + indicates the site is practicable as determined by criterion.
- indicates the site is not practicable as determined by criterion.
P indicates the option is practicable overall considering all criteria.
N indicates the option is not practicable overall considering all criteria.
It should be noted that the designation of practicable does not indicate that the use of a particular site for a specific future dredging project would be acceptable. Acceptability of disposal of a specific material at a specific site would still require a permit evaluation with appropriate testing and assessments.

(Sheet 1 of 3)

Table 24

Site/Criteria	Dredged Material NWS	CAX	NAVPHIBASE LCREEK Tributaries	NAVPHIBASE LCREEK Channel
NAVPHIBASE LCREEK Rifle Range				
Engineering				
Land use compatibility	-	-	-	-
Overall Feasibility	N	N	N	N
NAVIPHASE LCREEK Pier 60/ New Magazine				
Environmental				
Impacts to wetlands	+	+	+	+
Effluent quality	+	+	+	+
Engineering				
Operational suitability	+	+	+	+
Ponded area	+	+	+	+
Total volume	+	+	+	+
Dike construction	+	+	+	+
Land use compatibility	+	+	+	+
Economic	-	-	+	+
Overall Feasibility	N	N	P	P
NAVPHIBASE LCREEK Landfill				
Environmental				
Impacts to wetlands	+	+	+	+
Effluent quality	+	+	+	+
Engineering				
Operational suitability	+	+	+	+
Ponded area	+	+	+	+
Total volume	+	+	+	+
Dike construction	+	+	+	+
Land use compatibility*	-	-	-	-
Economic	-	-	+	+
Overall Feasibility	N	N	N	N

(Continued)

* During the review process for this report, environmental issues associated with Installation Restoration were investigated at the Landfill and Beach Drive sites. These sites will not be available for CDF construction until these issues are resolved. The data developed for CDF evaluations at these sites have been retained in this report.

(Sheet 2 of 3)

Table 24 (Concluded)

Site/Criteria	Dredged Material NWS	CAX	NAVPHIBASE LCREEK Tributaries	NAVPHIBASE LCREEK Channel
NAVPHIBASE LCREEK Beach Drive				
Environmental				
Impacts to wetlands	+	+	+	+
Effluent quality	+	+	+	+
Engineering				
Operational suitability	+	+	+	+
Ponded area	+	+	+	+
Total volume	+	+	+	+
Dike construction	+	+	+	+
Land use compatibility*	-	-	-	-
Economic	-	-	+	+
Overall Feasibility	N	N	N	N

* During the review process for this report, environmental issues associated with Installation Restoration were investigated at the Landfill and Beach Drive sites. These sites will not be available for CDF construction until these issues are resolved. The data developed for CDF evaluations at these sites have been retained in this report.

(Sheet 3 of 3)

Table 25

Feasibility Summary for Beneficial Use Options*

Site/Criteria	Dredged Material NWS	CAX	NAVPHIBASE LCREEK Tributaries	NAVPHIBASE LCREEK Channel
CAX Shoreline Protection				
Environmental				
Contaminant release	+	+	+	+
Engineering				
Like on like	-	-	-	+
Grain size	-	-	-	+
Economic	+	+	+	+
Overall Feasibility	N	N	N	P
NAVPHIBASE LCREEK Beach Nourishment				
Environmental				
Contaminant release	+	+	+	+
Engineering				
Like on like	-	-	-	+
Grain size	-	-	-	+
Economic	+	+	+	+
Overall Feasibility	N	N	N	P

* + indicates the site is practicable as determined by criterion.
- indicates the site is not practicable as determined by criterion.
P indicates the option is practicable overall considering all criteria.
N indicates the option is not practicable overall considering all criteria.
It should be noted that the designation of practicable does not indicate that the use of a particular site for a specific future dredging project would be acceptable. Acceptability of disposal of a specific material at a specific site would still require a permit evaluation with appropriate testing and assessments.

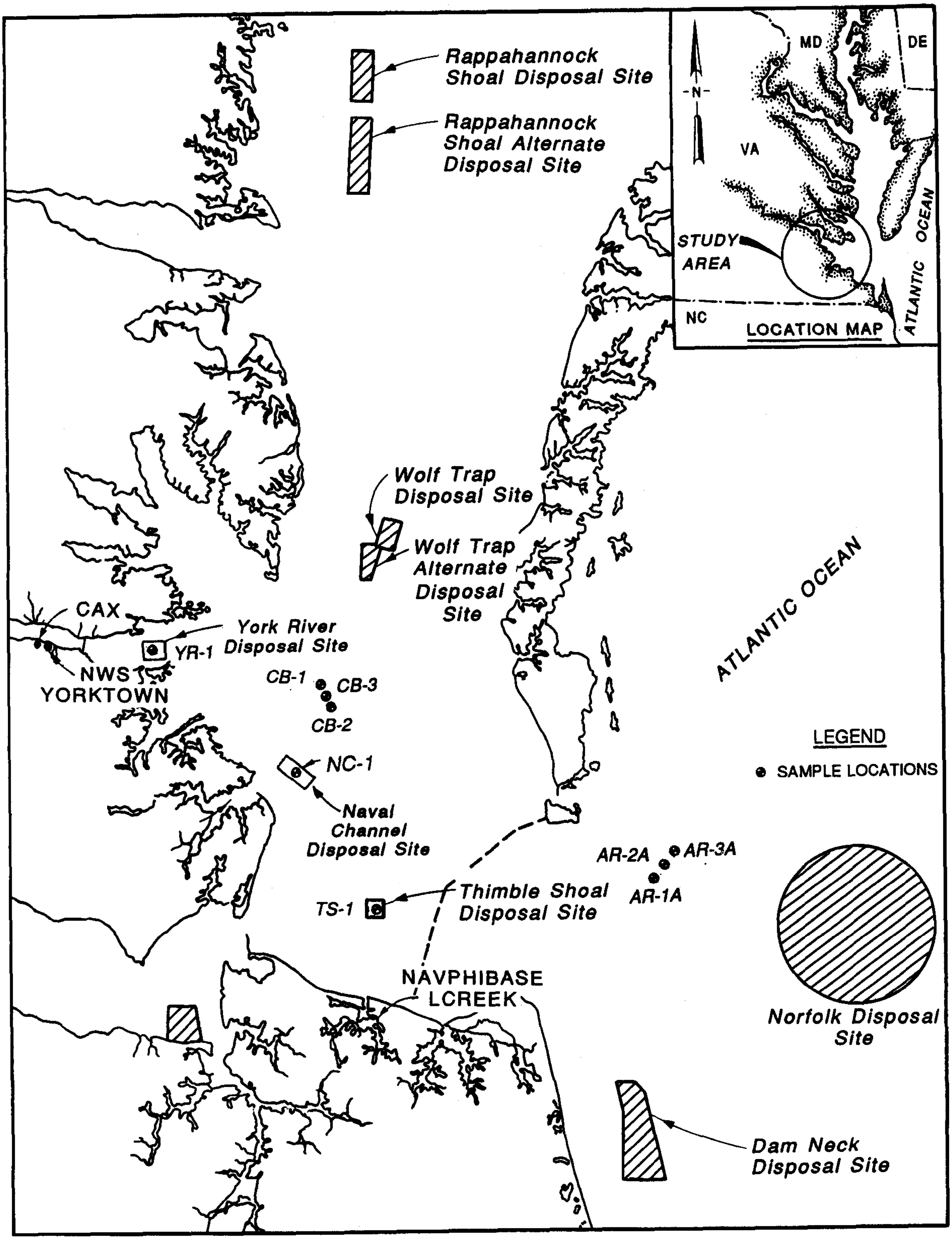


Figure 1. Locations of Naval Weapons Station, Yorktown; Naval Supply Center, Cheatham Annex; Naval Amphibious Base, Little Creek, and open-water disposal sites

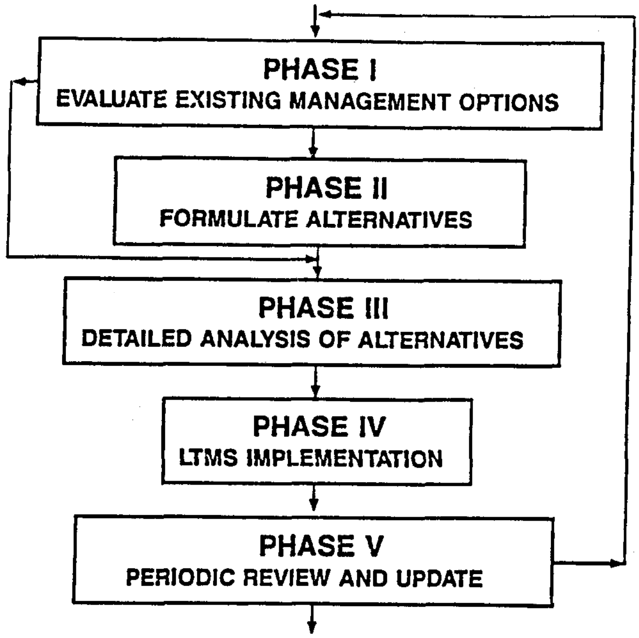


Figure 2. Phases of the Long-term Management Strategy process (Francingues and Mathis 1990)

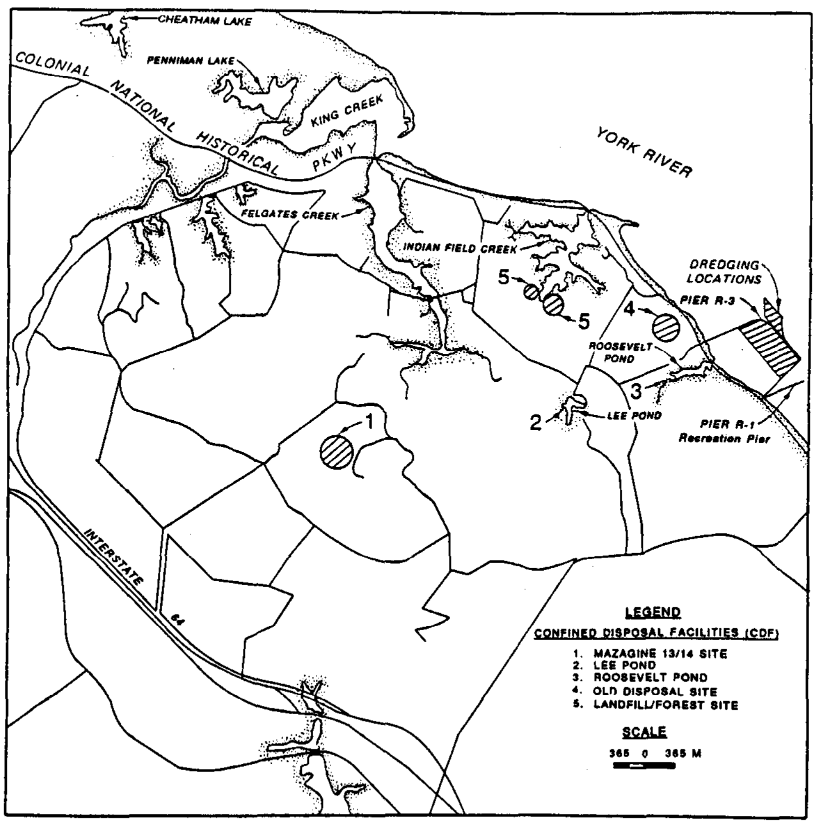


Figure 3. Naval Weapons Station, Yorktown, and possible confined disposal facilities

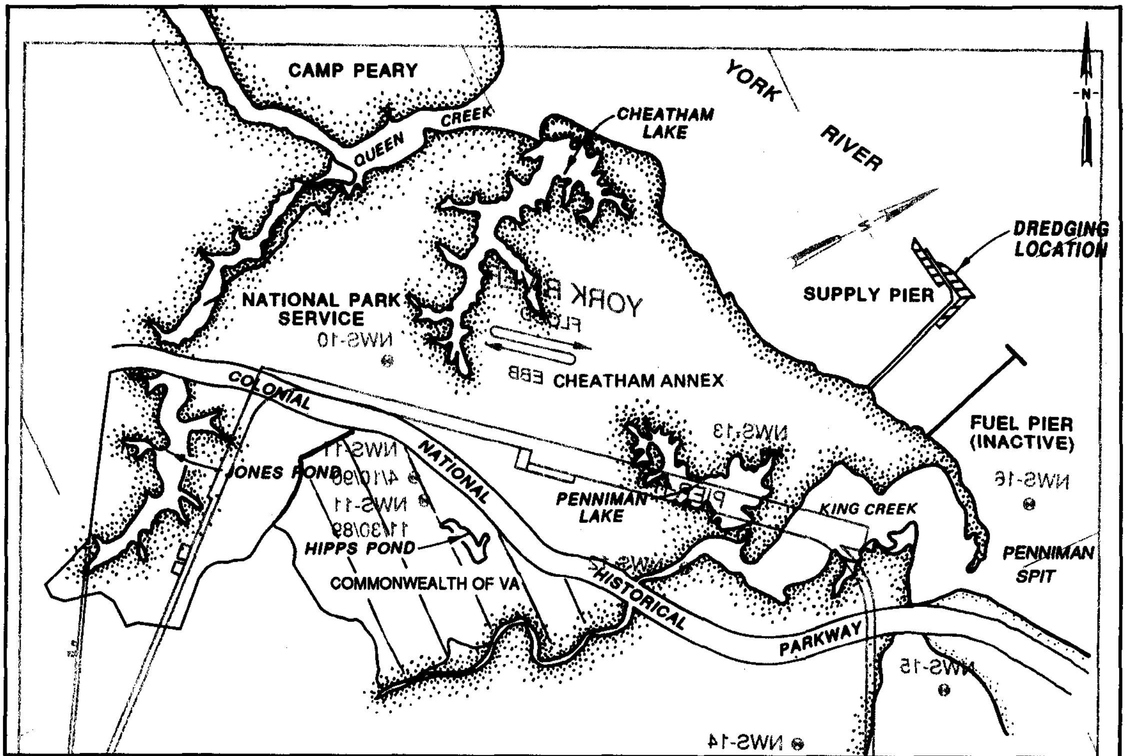


Figure 4. Naval Supply Center, Cheatham Annex

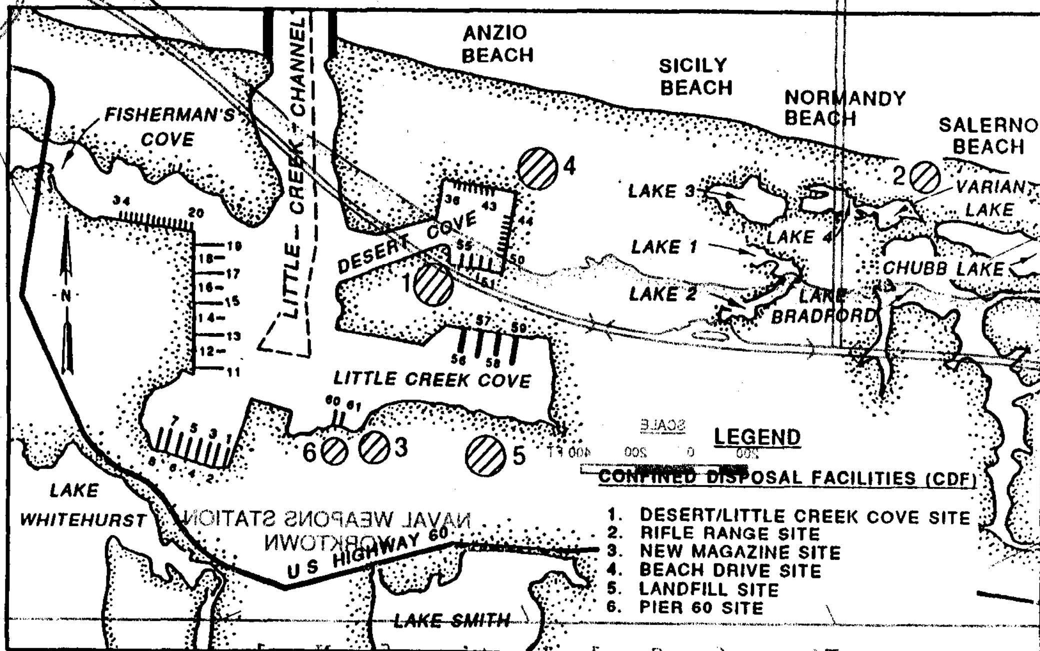


Figure 5. Naval Amphibious Base, Little Creek, and possible confined disposal facilities

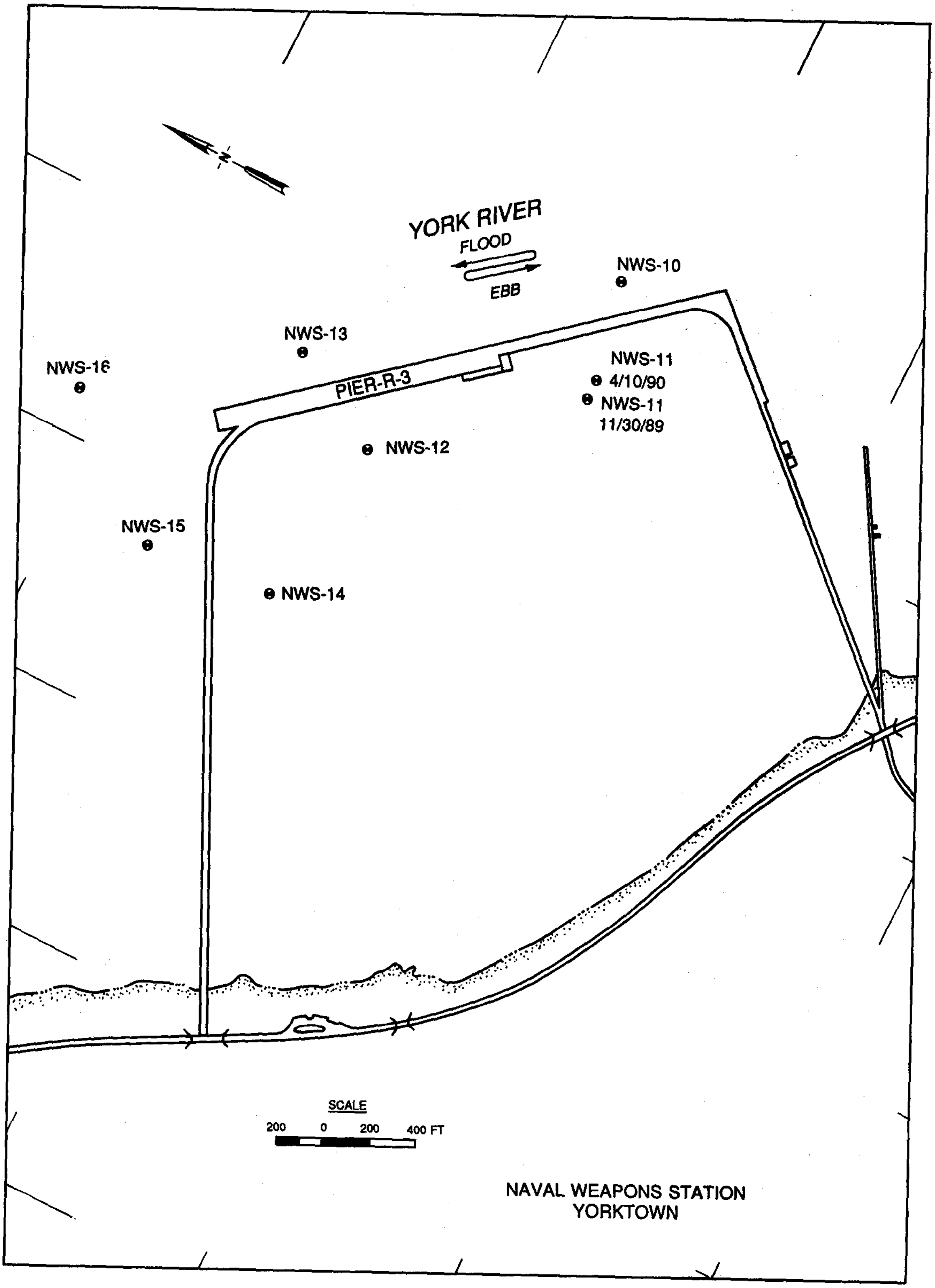


Figure 6. Sample locations for Naval Weapons Station, Yorktown

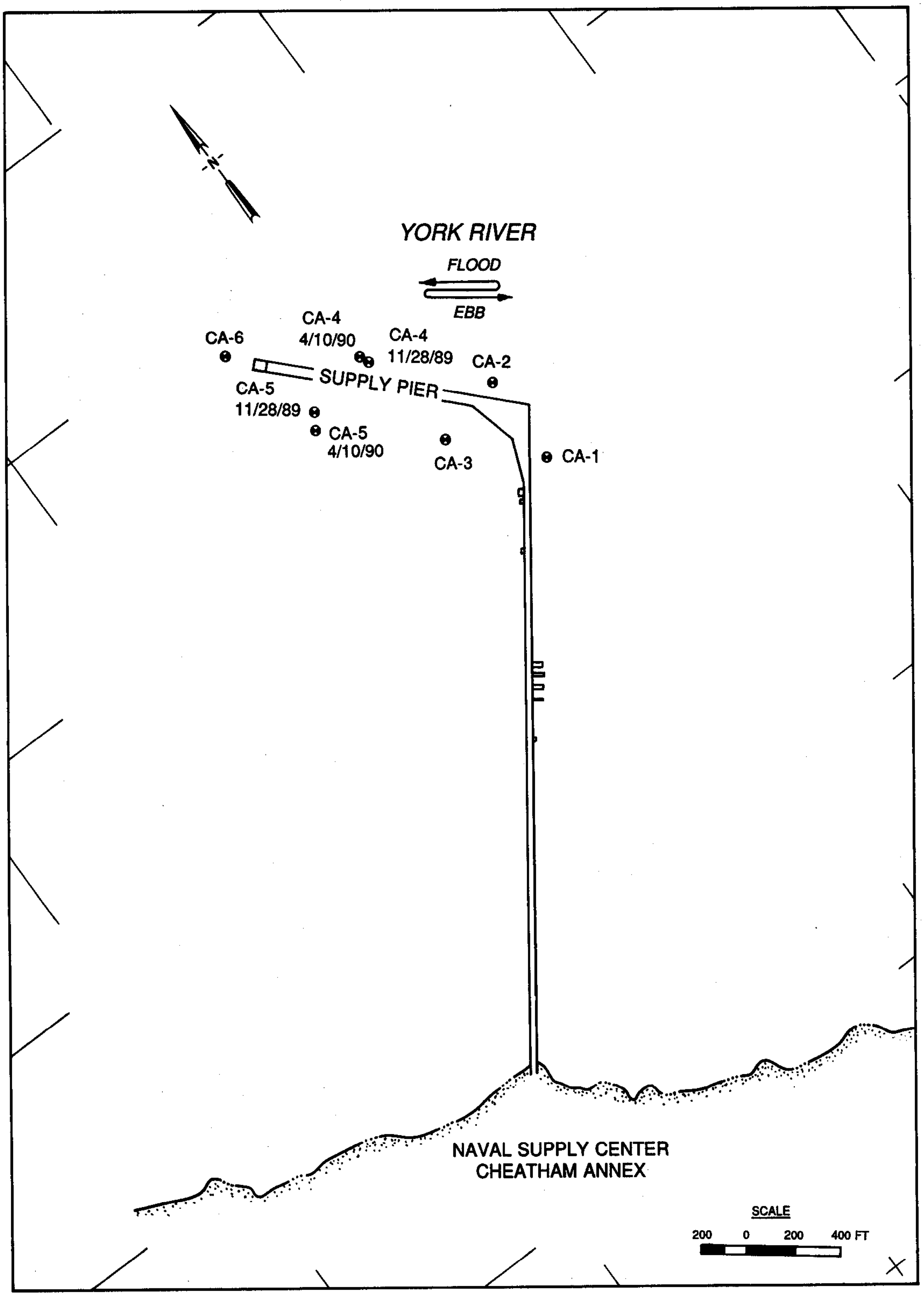


Figure 7. Sample locations for Naval Supply Center, Cheatham Annex

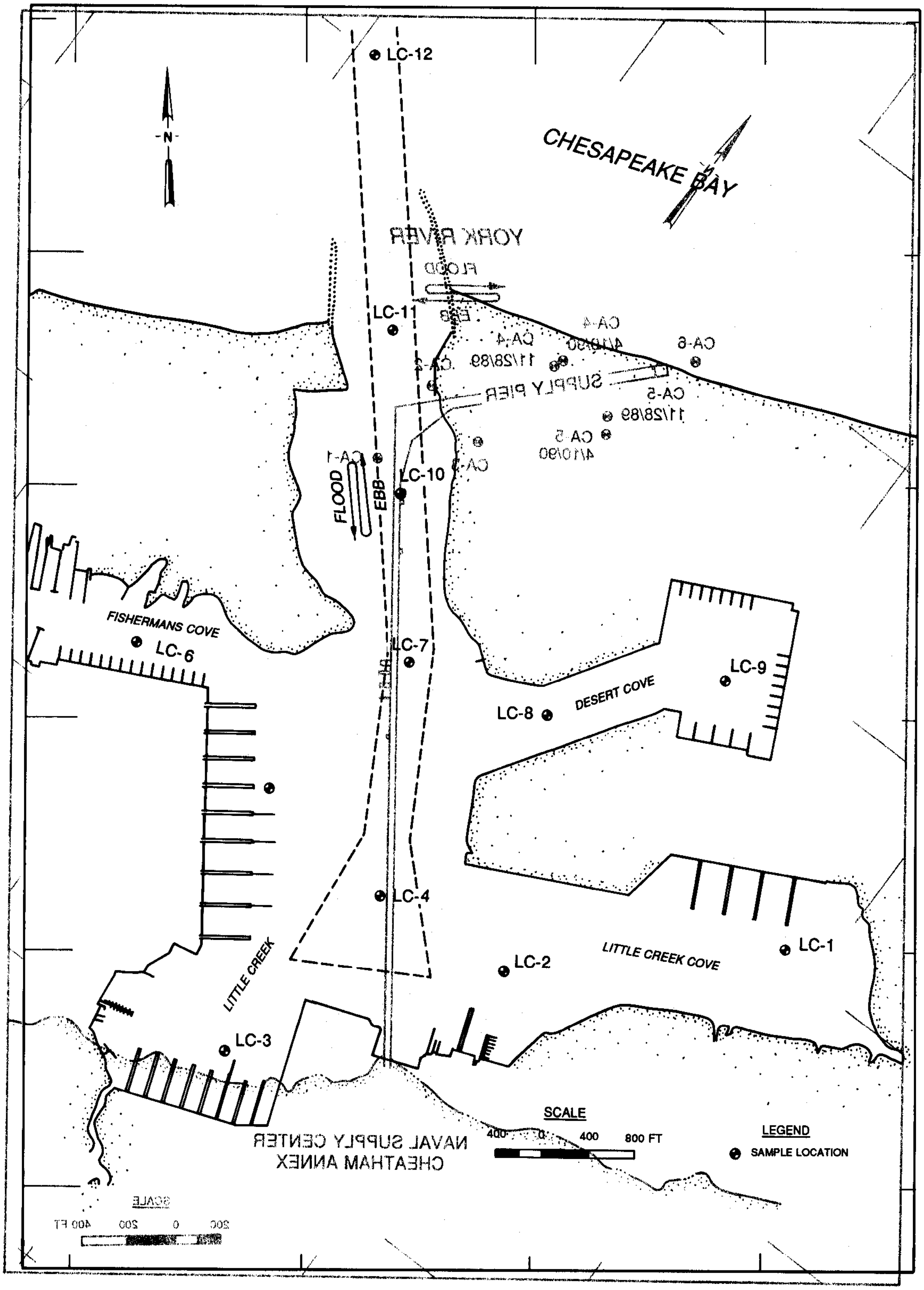


Figure 8. Sample locations for Naval Amphibious Base, Little Creek

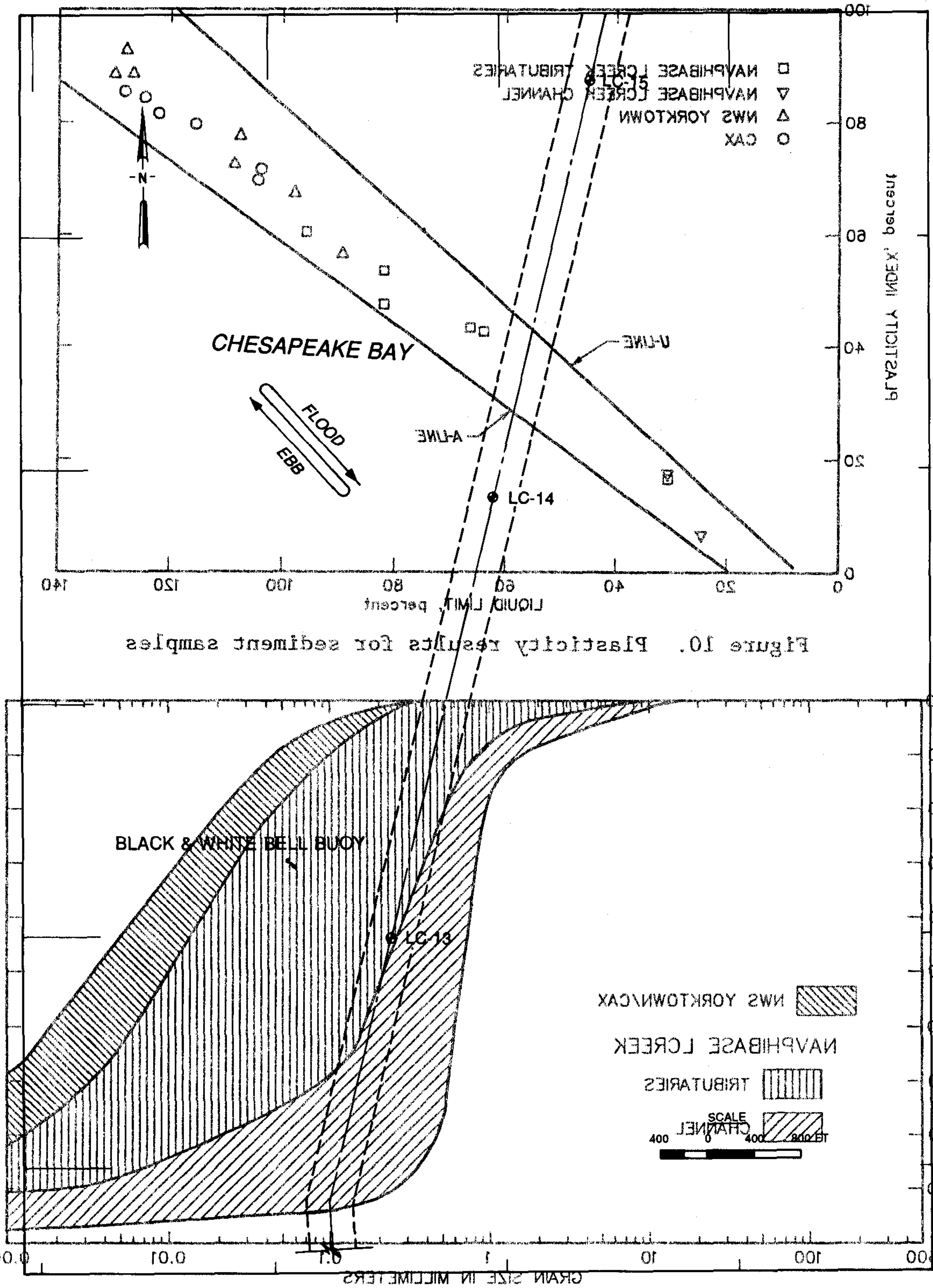


Figure 9. Additional sample locations for Naval Amphibious Base, Little Creek

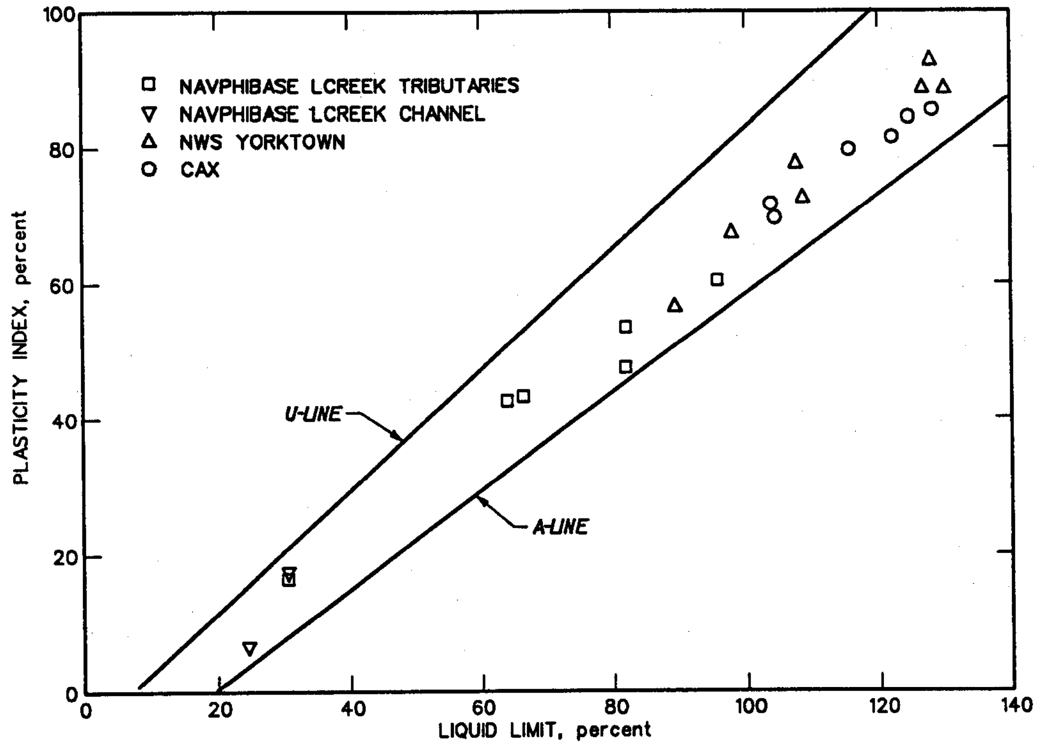


Figure 10. Plasticity results for sediment samples

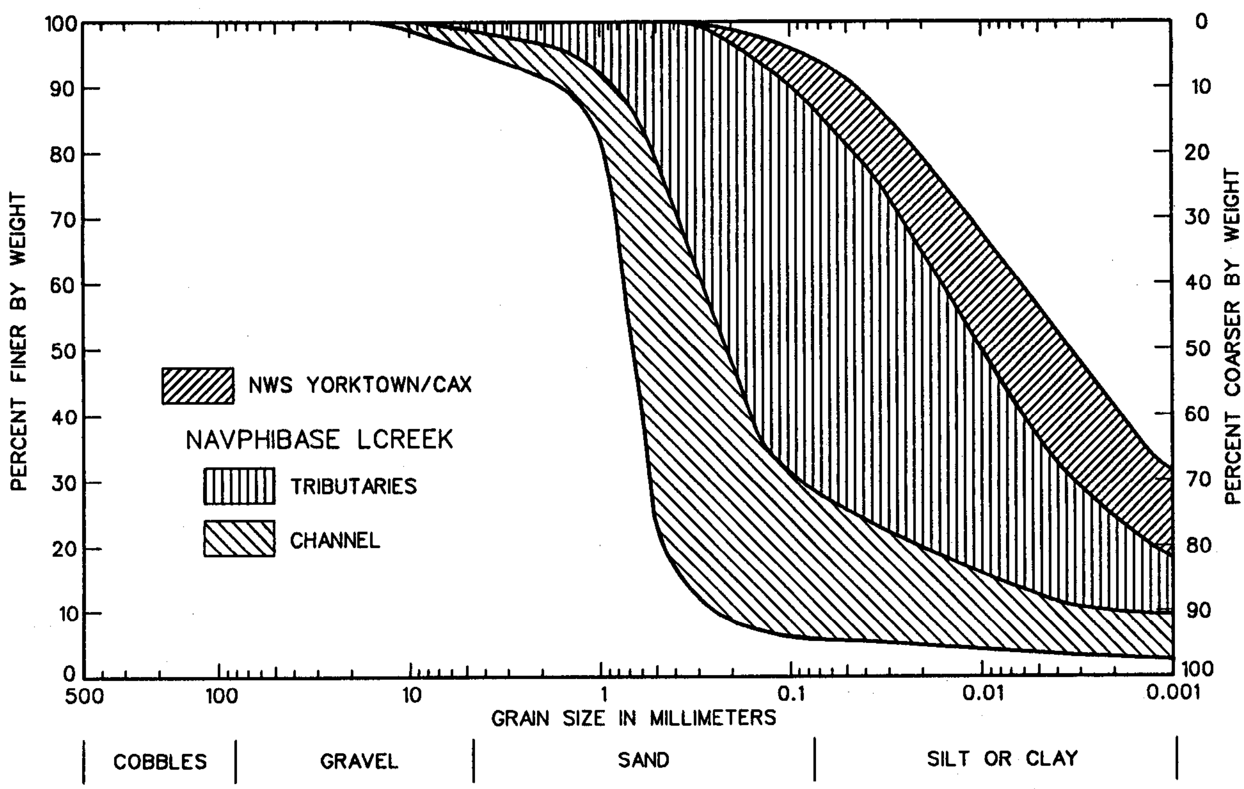


Figure 11. Grain-size distribution ranges for sediment samples

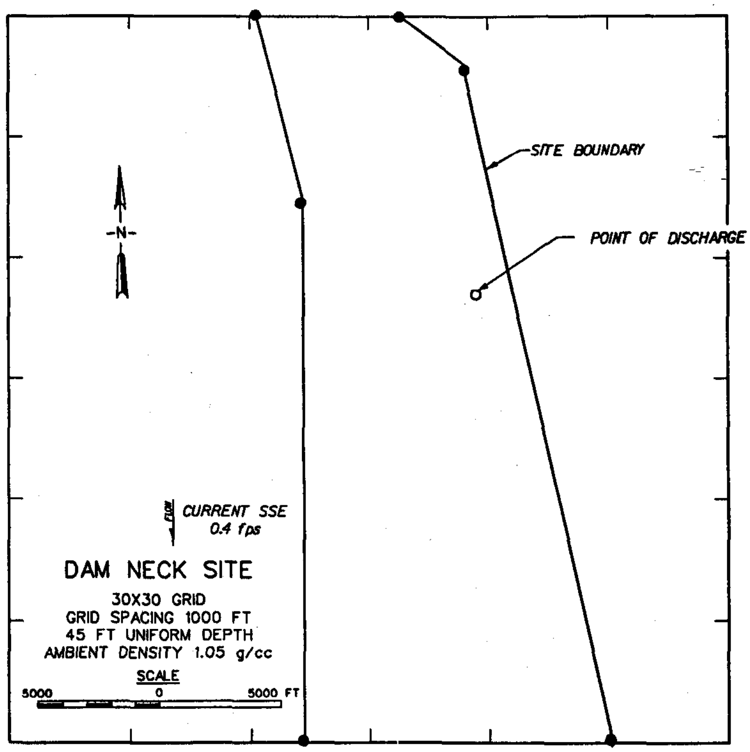


Figure 12. Plan of Dam Neck site

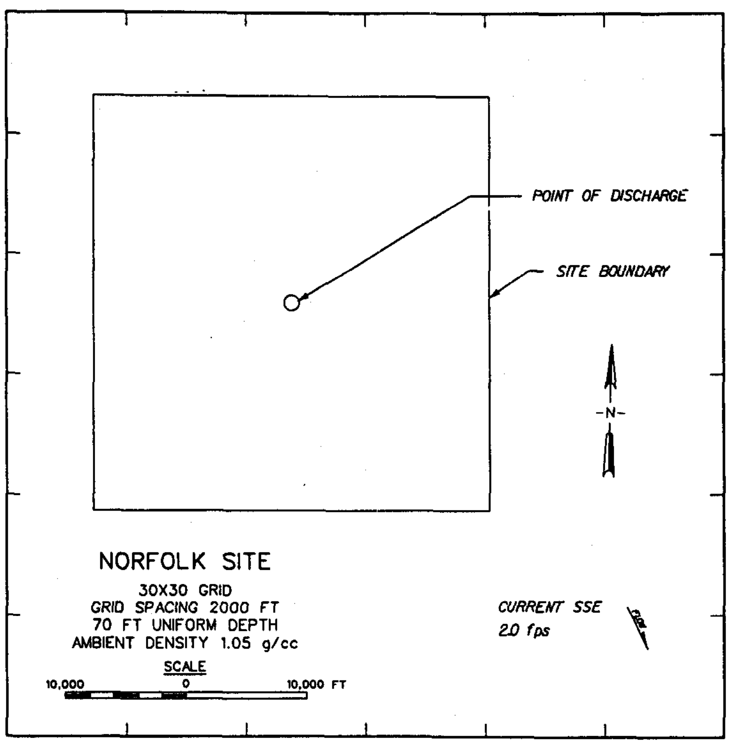


Figure 13. Plan of Norfolk site

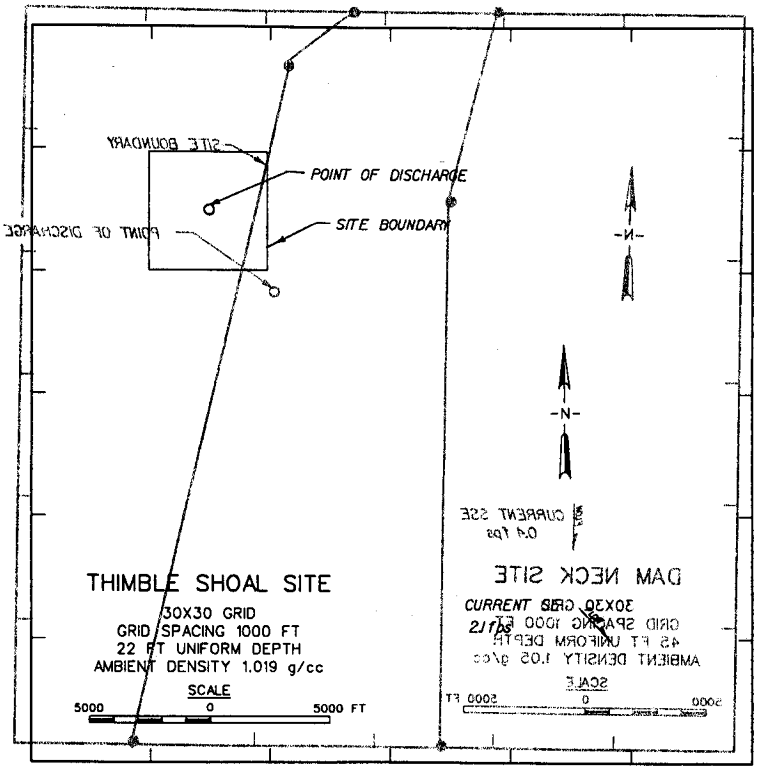


Figure 14. Plan of Thimble Shoal site

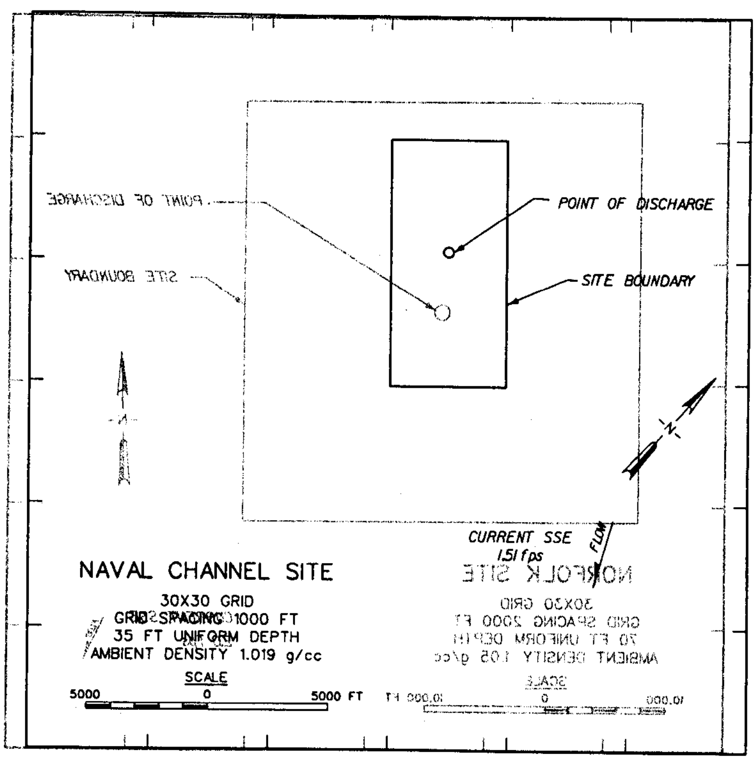


Figure 15. Plan of Naval Channel site

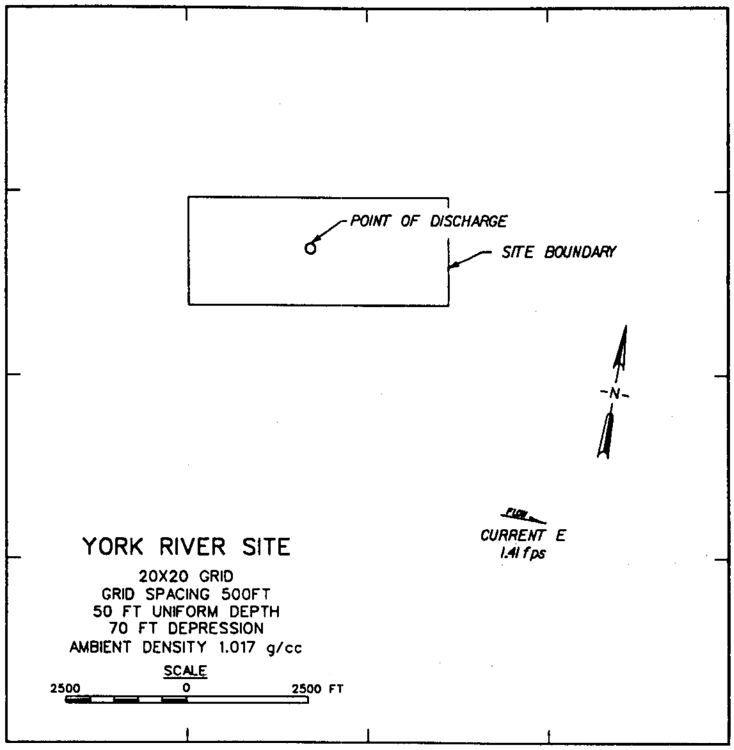


Figure 16. Plan of York River site

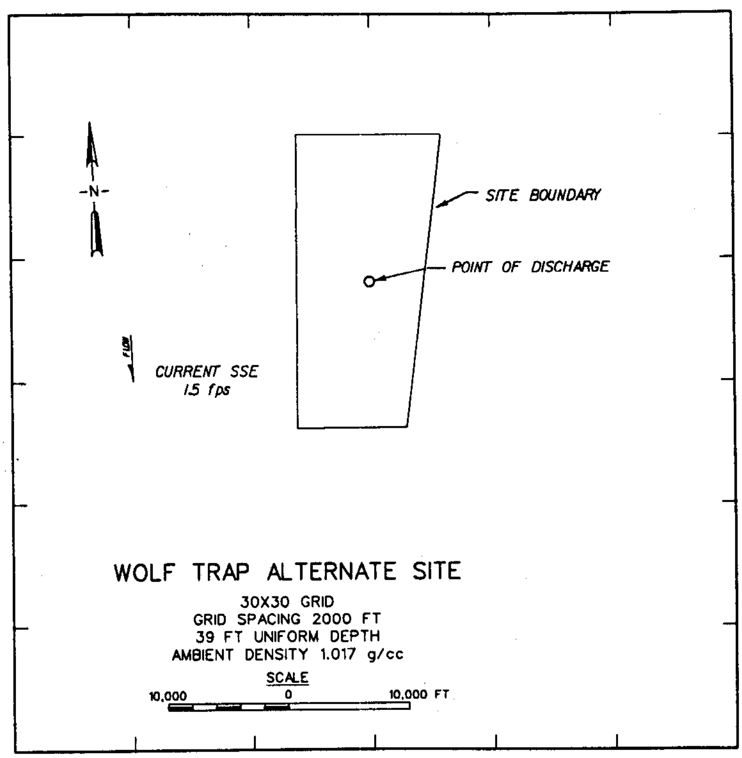


Figure 17. Plan of Wolf Trap Alternate site

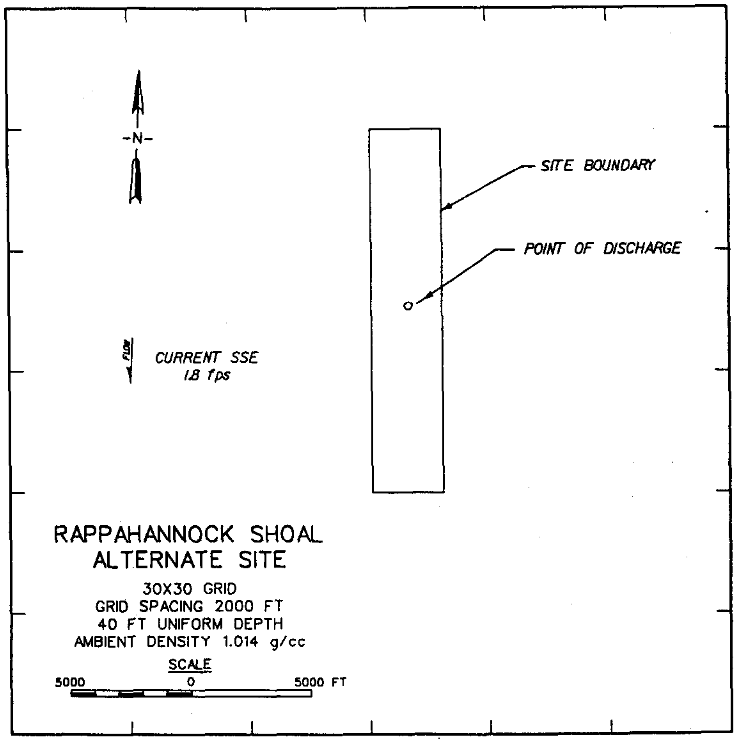


Figure 18. Plan of Rappahanock Shoal Alternate site

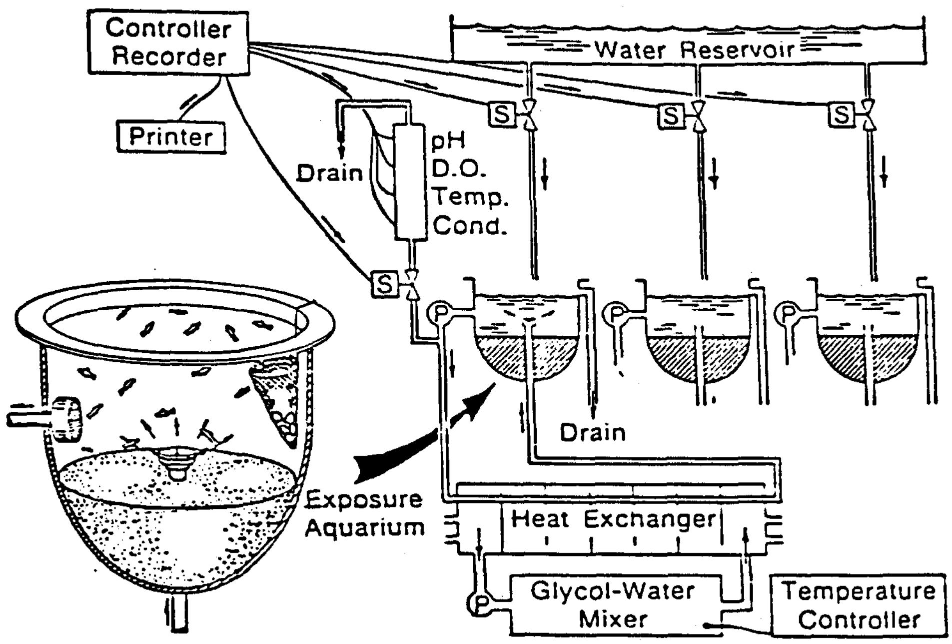


Figure 19. Schematic of flow-through aquatic toxicology exposure system

...MULTIPLY DISPLAYED VALUES BY 0.1000E-02 (LEGEND... + = .LT. .01 . = .

M N=	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2	0000000000000000000000000000000000000000000000000000000000000000000000000																		
3	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.6	0	0	0
11	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.6	0	0	0
12	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	1.4	0	0	0	0
13	0000	0	0	0	0	0	0	0	0	0	0	0	.07	.24	1.6	0	0	0	0
14	0000	0	0	0	0	0	0	0	0	0	0	0	.25	.43	.43	0	0	0	0
15	0000	0	0	0	0	0	0	0	0	0	0	0	.25	.25	.25	0	0	0	0
16	0000	0	0	0	0	0	0	0	0	0	0	0	.07	.07	.07	0	0	0	0
17	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 20. Model results for NWS Yorktown sediment placed at Naval Channel site, showing total thickness of accumulated material in feet on the bottom for one barge load

...MULTIPLY DISPLAYED VALUES BY 0.1000E-03 (LEGEND... + = .LT. .01 . = .

M N=	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2	0000000000000000000000000000000000000000000000000000000000000000000000000																		
3	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0000	0	0	0	0	0	0	0	0	0	0	0	.	.	.	0	0	0	0
12	0000	0	0	0	0	0	0	0	0	0	.	+	+	+	+	.	0	0	0
13	0000	0	0	0	0	0	0	0	0	.	+	.01	.13	.18	.04	+	.	0	0
14	0000	0	0	0	0	0	0	0	0	.	+	.20	1.6	2.3	.56	.02	+	0	0
15	0000	0	0	0	0	0	0	0	0	.	+	.43	3.6	5.1	1.2	.04	+	0	0
16	0000	0	0	0	0	0	0	0	0	.	+	.16	1.3	1.8	.44	.01	+	0	0
17	0000	0	0	0	0	0	0	0	0	0	+	+	.08	.11	.02	+	.	0	0
18	0000	0	0	0	0	0	0	0	0	0	.	+	+	+	+	.	0	0	0
19	0000	0	0	0	0	0	0	0	0	0	0	0	.	.	0	0	0	0	0
20	0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 21. Model results for NWS Yorktown material placed at Naval Channel site, showing plume concentrations in cubic feet of clay-silt per cubic foot of water at mid-depth after 1-hr initial mixing period

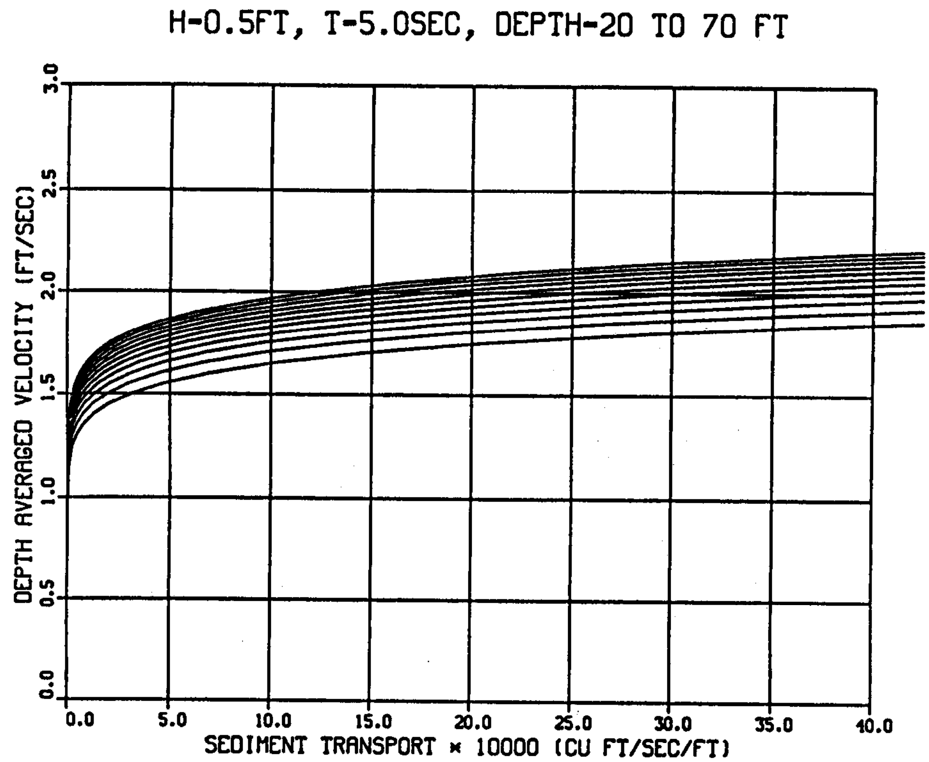


Figure 22. Sediment transport-velocity relationship for D_{50} - 0.0625 mm

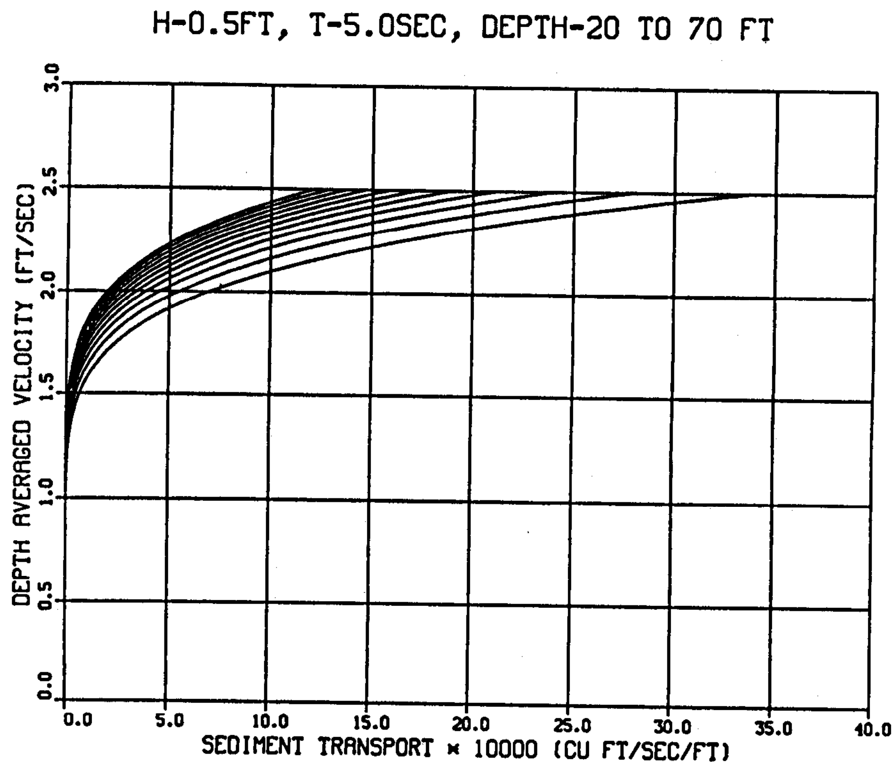


Figure 23. Sediment transport-velocity relationship for D_{50} = 0.140 mm

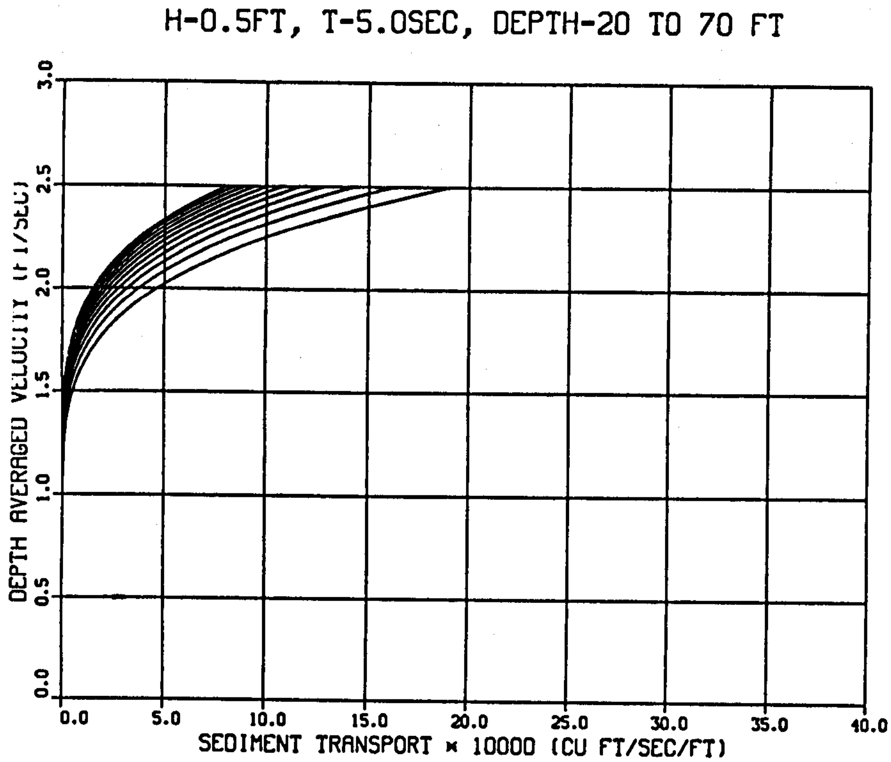


Figure 24. Sediment transport-velocity relationships for $D_{50} = 0.200$ mm

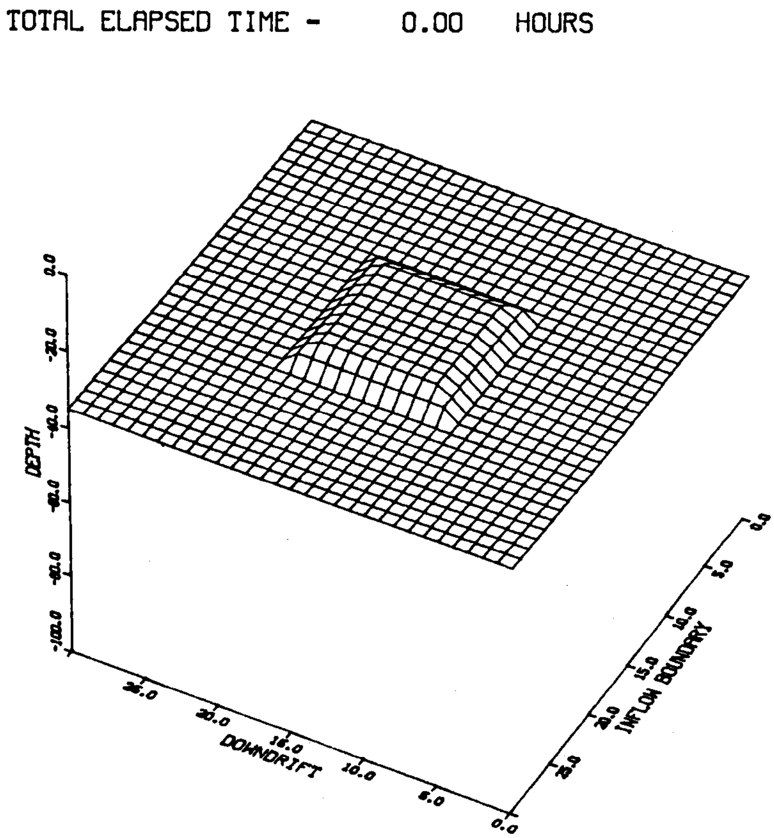


Figure 25. Example (Naval Channel) idealized disposal mound perspective view

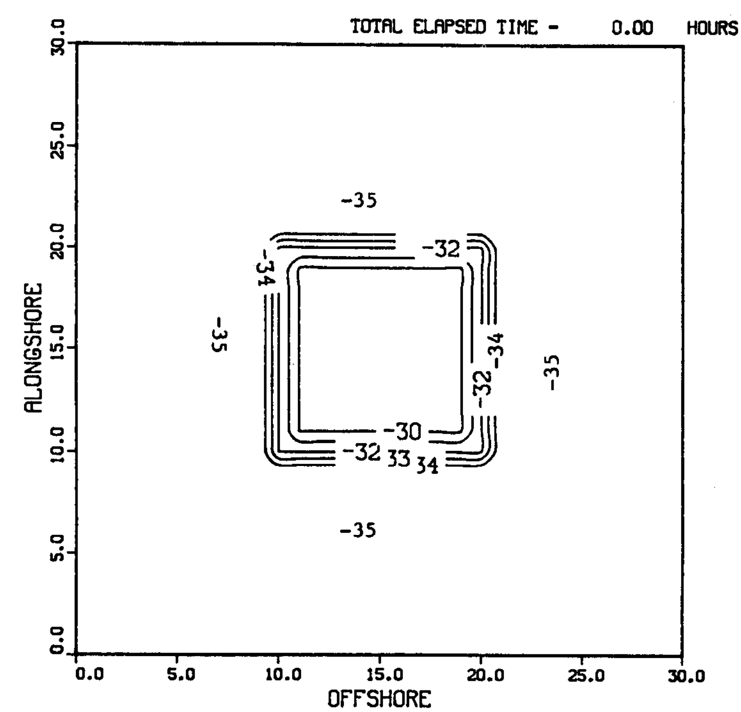


Figure 26. Example (Naval Channel) idealized disposal mound contour map

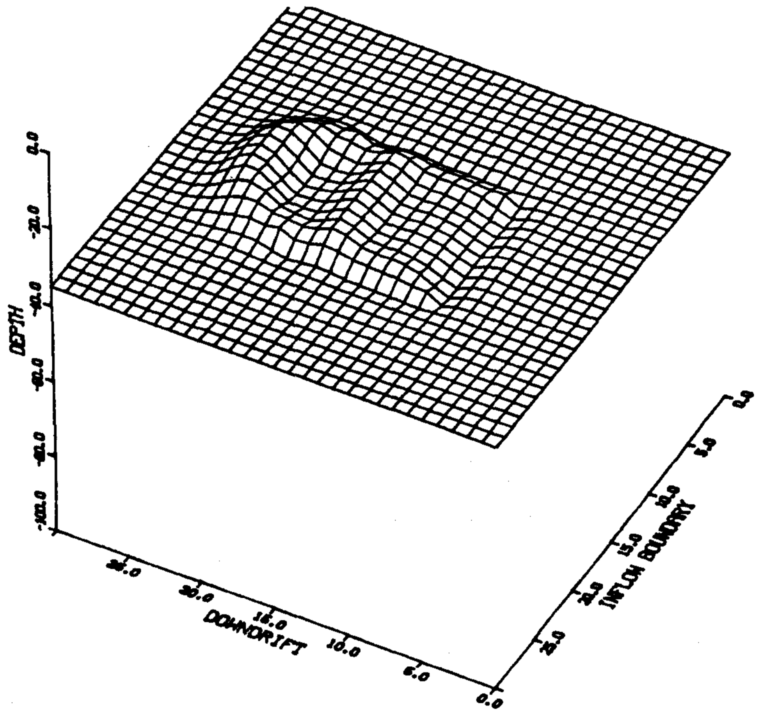


Figure 27. Long-term simulation mound axis migration history at example (Naval Channel) disposal site after 3 months (2,008 hr) with material from either Naval Weapons Station or Naval Supply Center

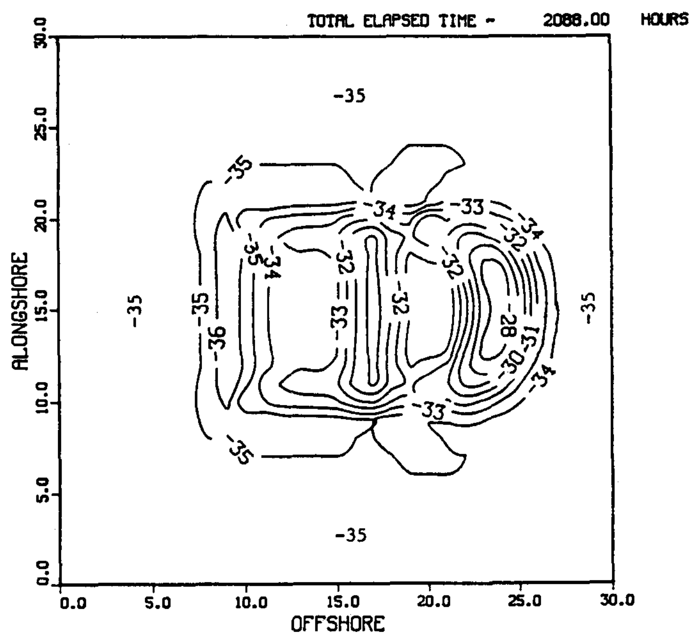


Figure 28. Long-term simulation contours after mound axis migration at example (Naval Channel) disposal site after 3 months (2,008 hr) with material from either Naval Weapons Station or Naval Supply Center

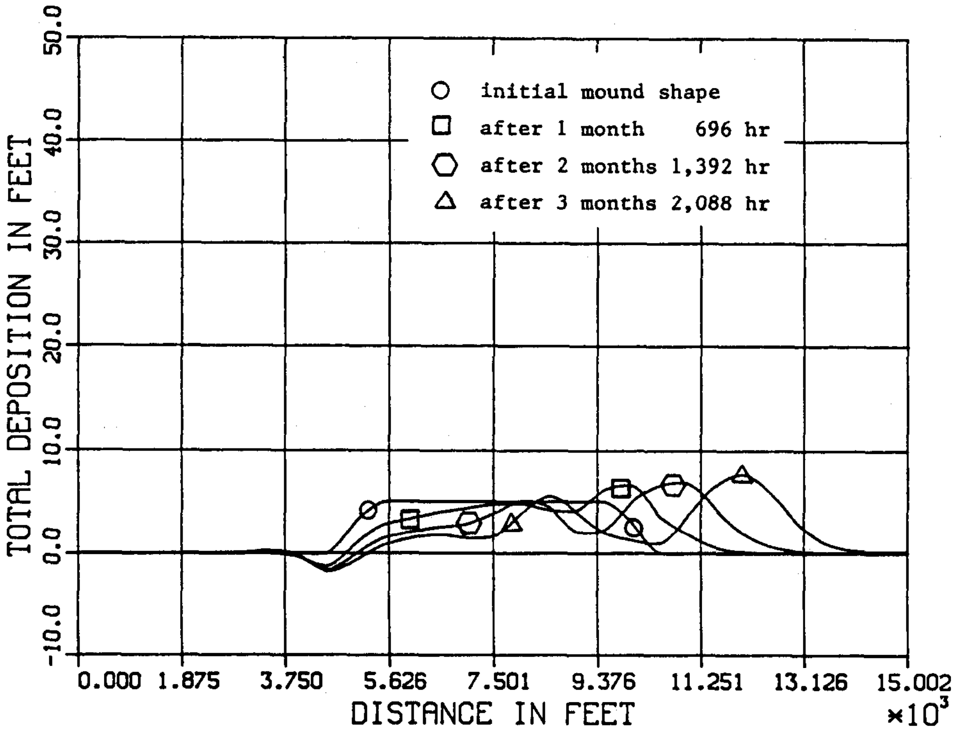


Figure 29. Long-term simulation mound centerline axis migration for 3-month time-history at example (Naval Channel) disposal site with material from either Naval Weapons Station or Naval Supply Center

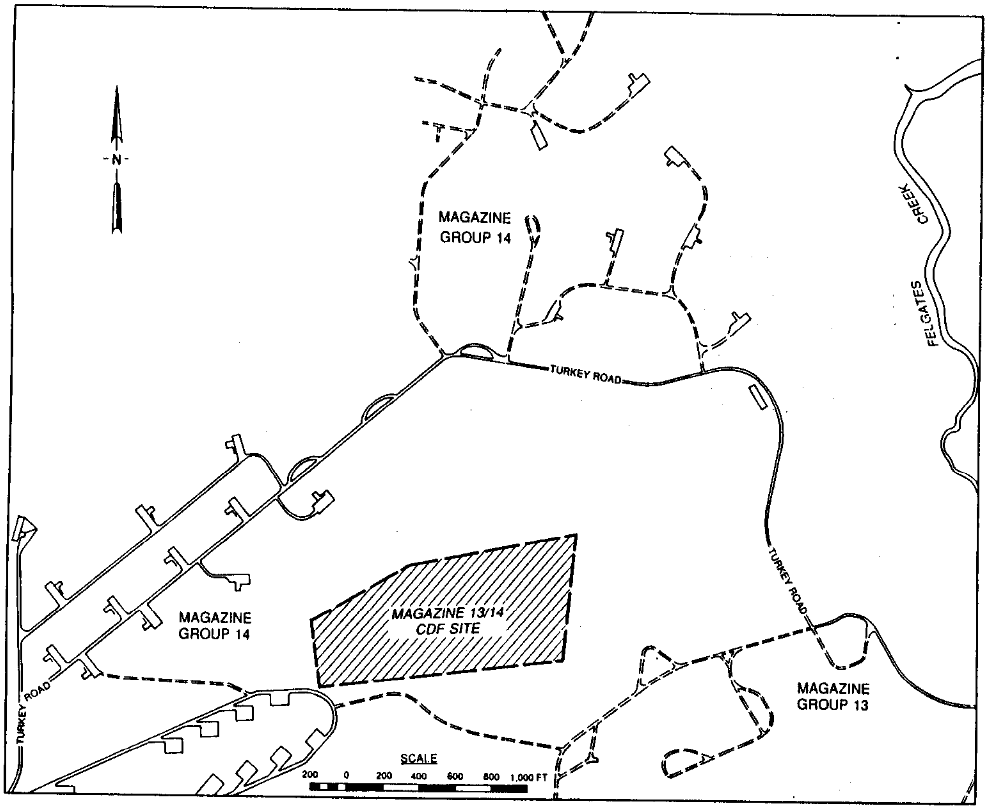


Figure 30. Plan of Magazine 13-14 site

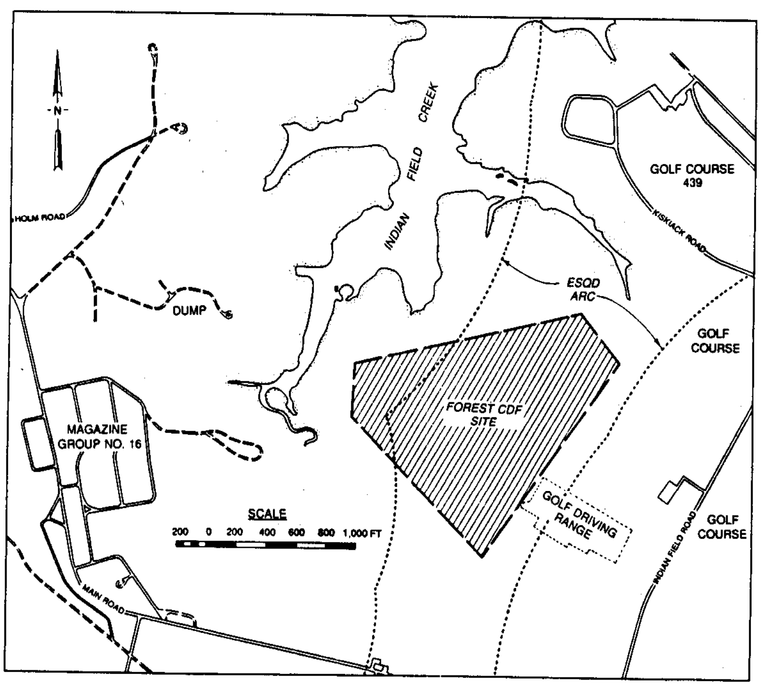


Figure 31. Plan of Forest site

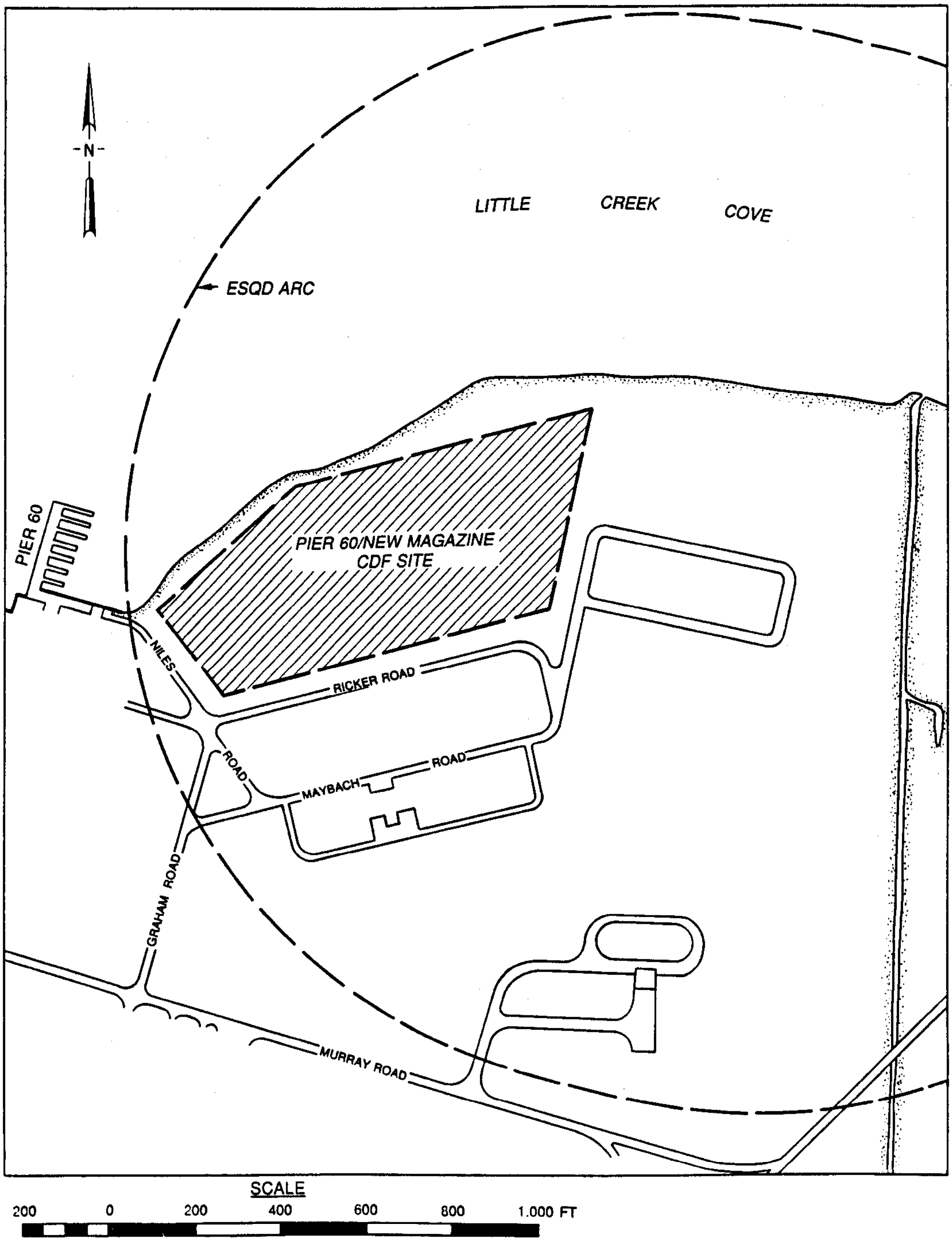


Figure 32. Plan of Pier 60/New Magazine site

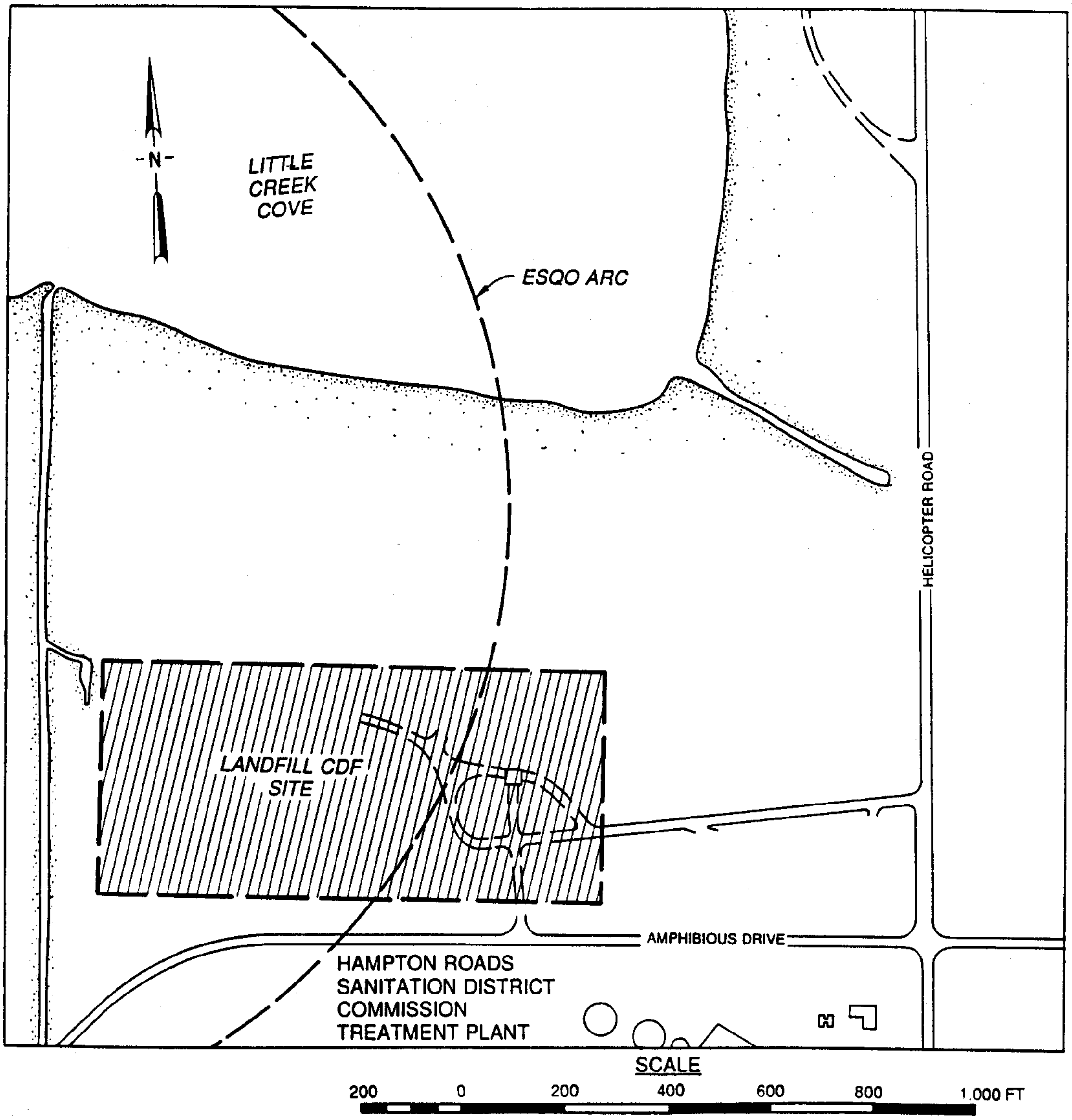


Figure 33. Plan of Landfill site

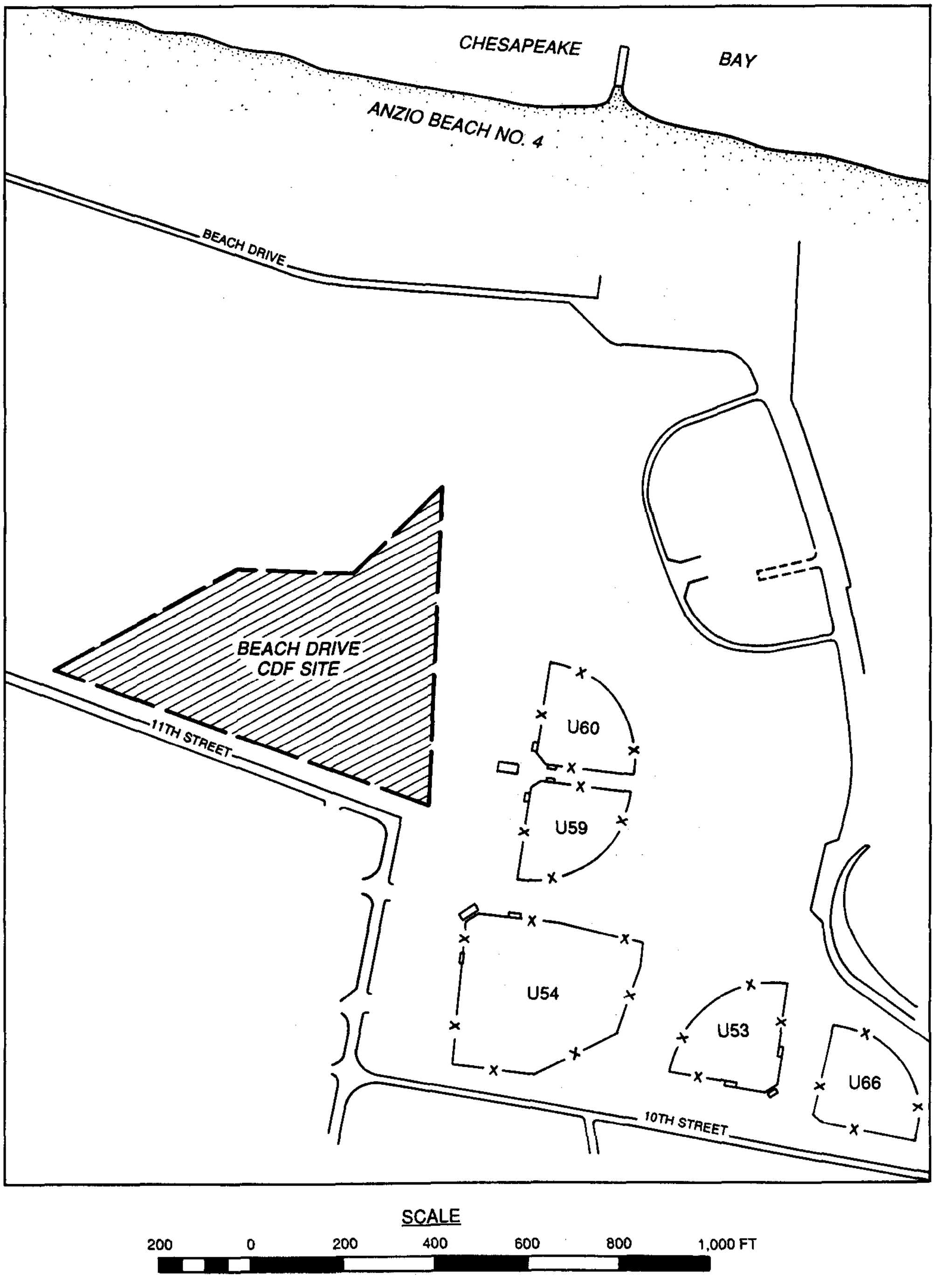


Figure 34. Plan of Beach Drive site

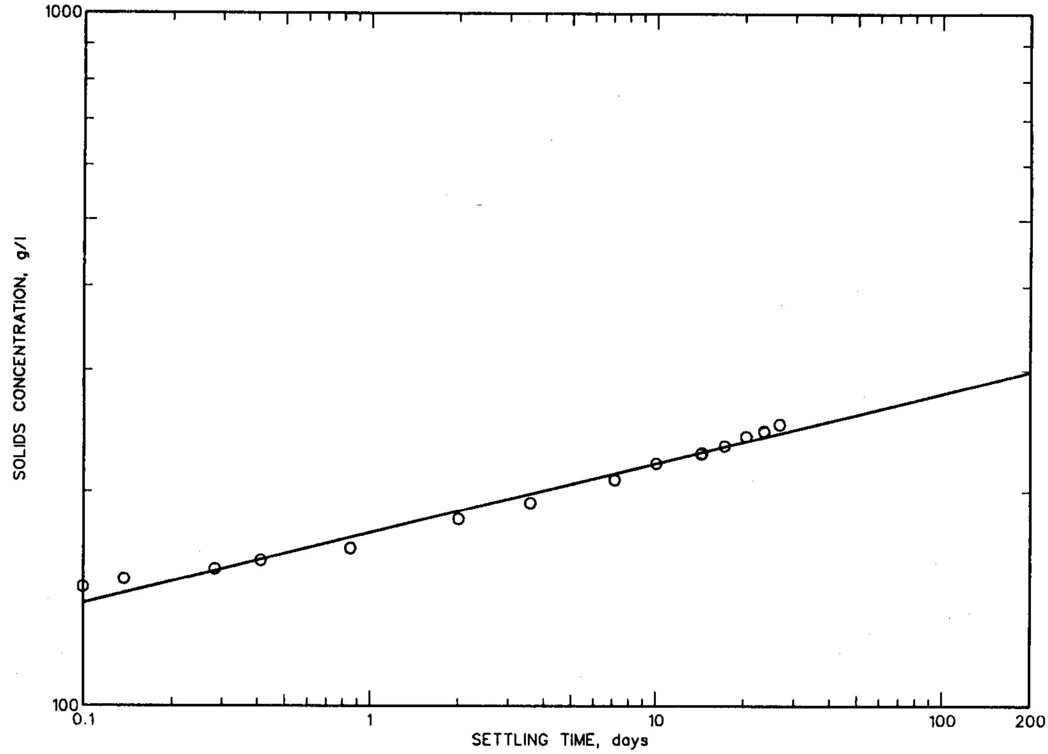


Figure 35. Compression settling test results for NWS Yorktown/CAX

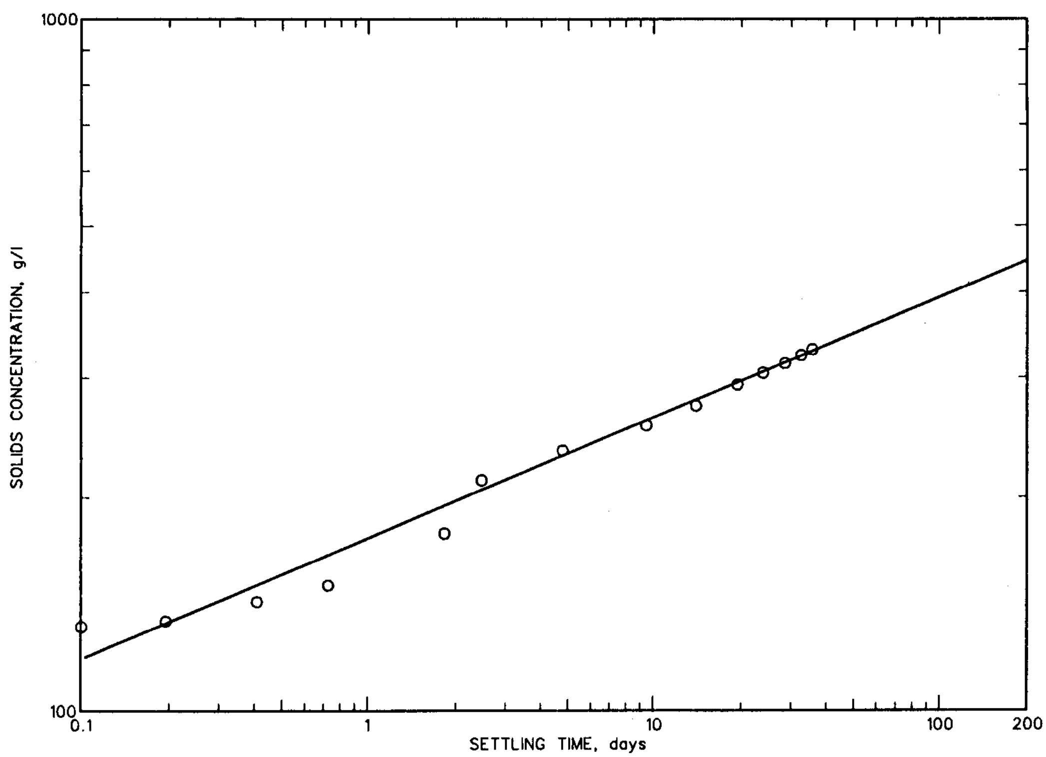


Figure 36. Compression settling test results for NAVPHIBASE LCREEK

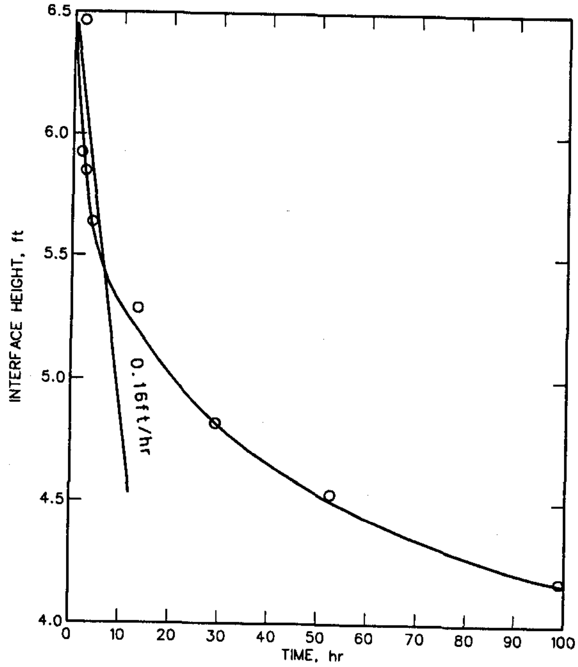
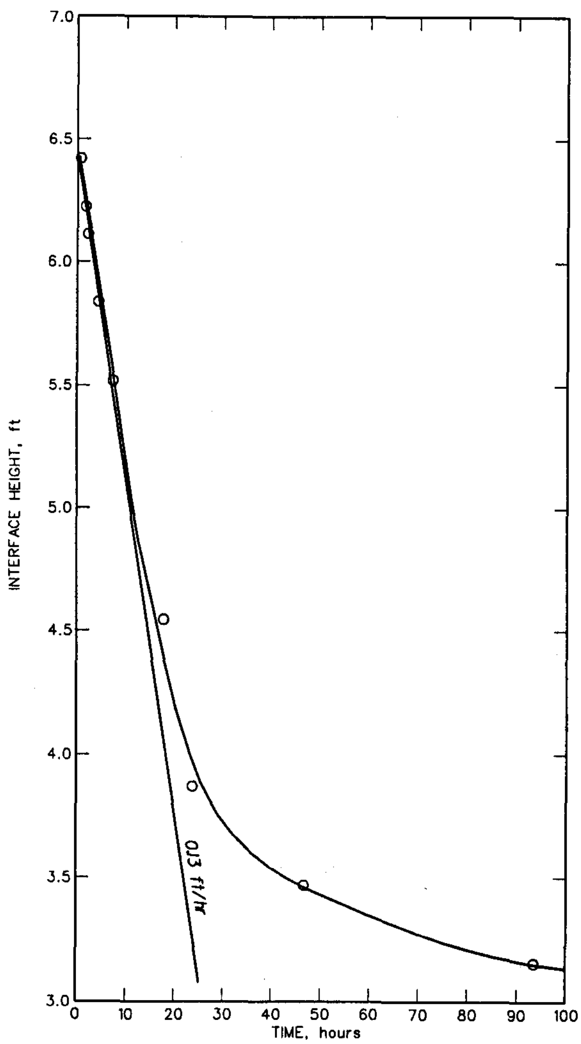


Figure 37. Zone settling test results for NWS Yorktown/CAX

Figure 38. Zone settling test results for NAVPHIBASE LCREEK



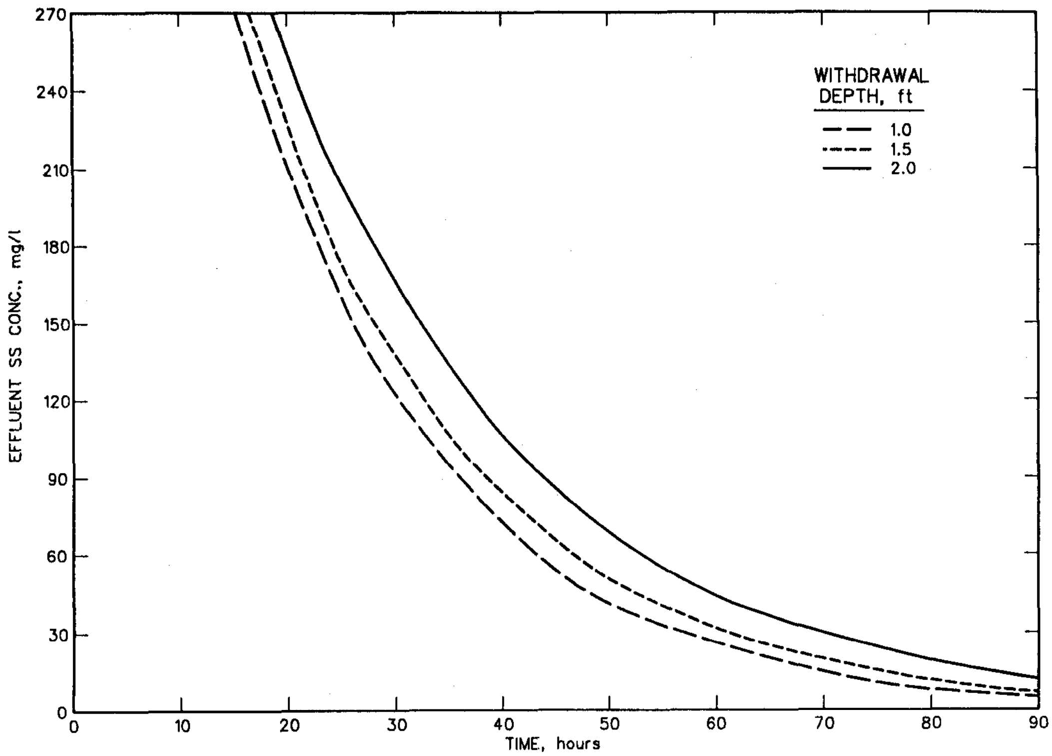


Figure 39. Flocculent settling test results for NWS Yorktown/CAX

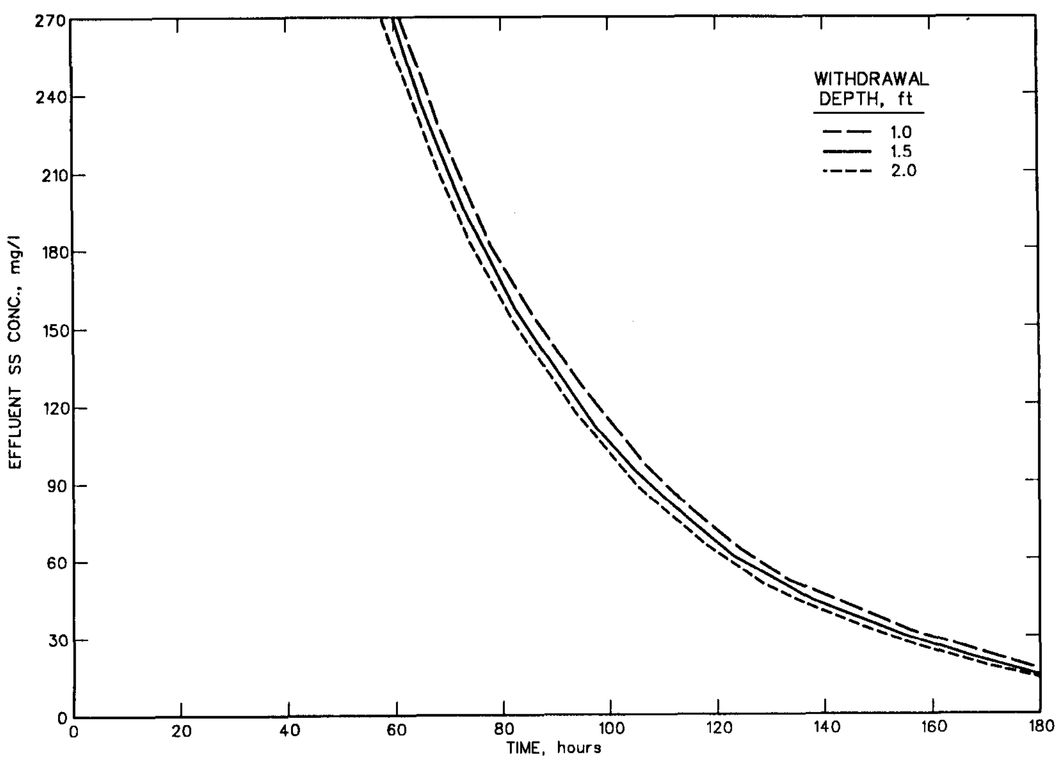


Figure 40. Flocculent settling test results for NAVPHIBASE LCREEK

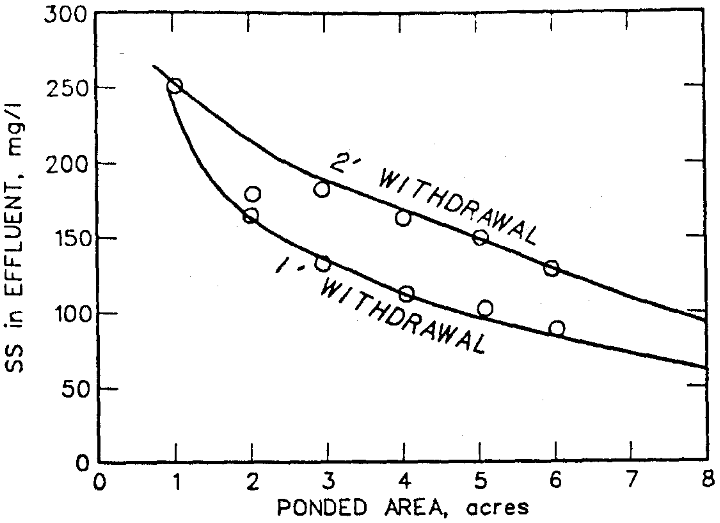


Figure 41. Effect of ponded depth and average withdrawal depth on effluent suspended solids for NWS Yorktown/CAX

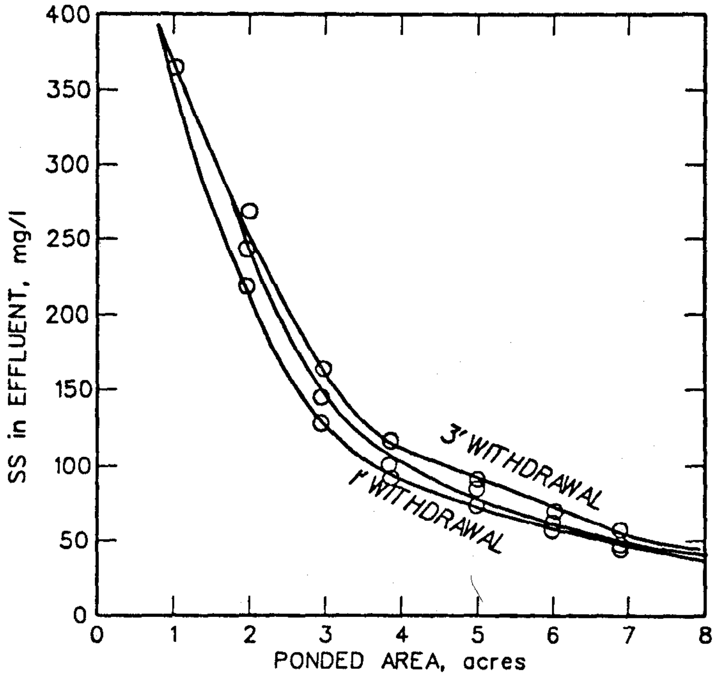


Figure 42. Effect of ponded depth and average withdrawal depth on effluent suspended solids for NAVPHIBASE LCREEK

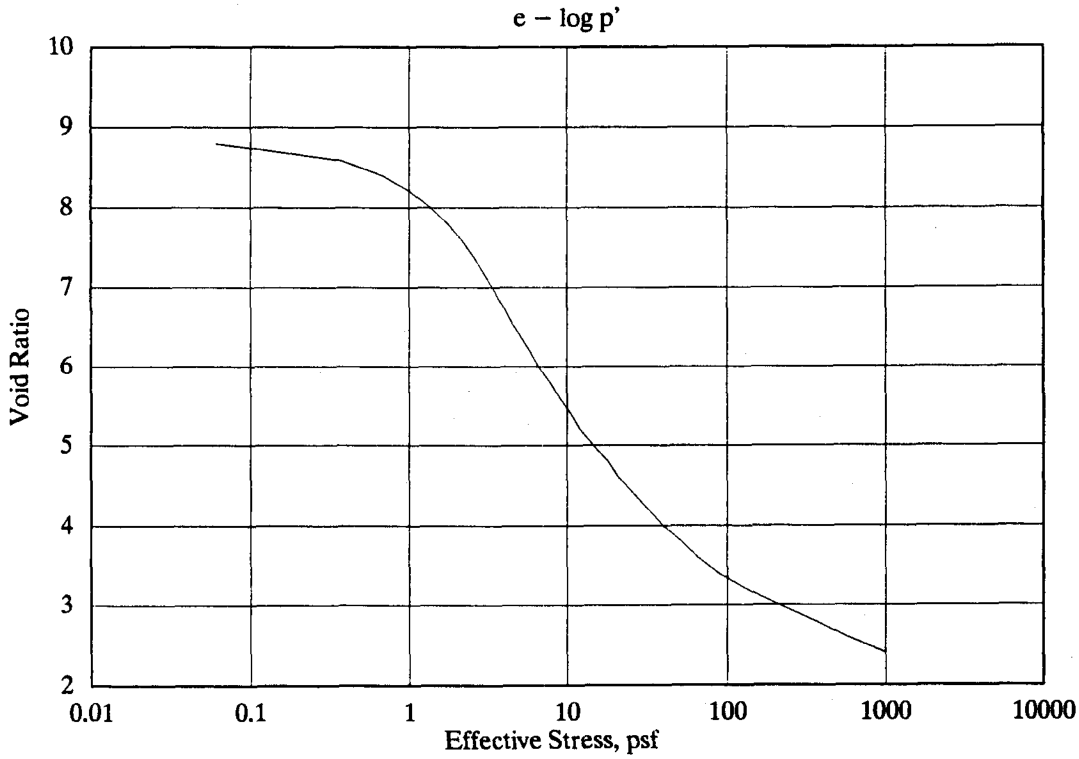


Figure 43. Void ratio-effective stress relationship for NWS Yorktown sediment

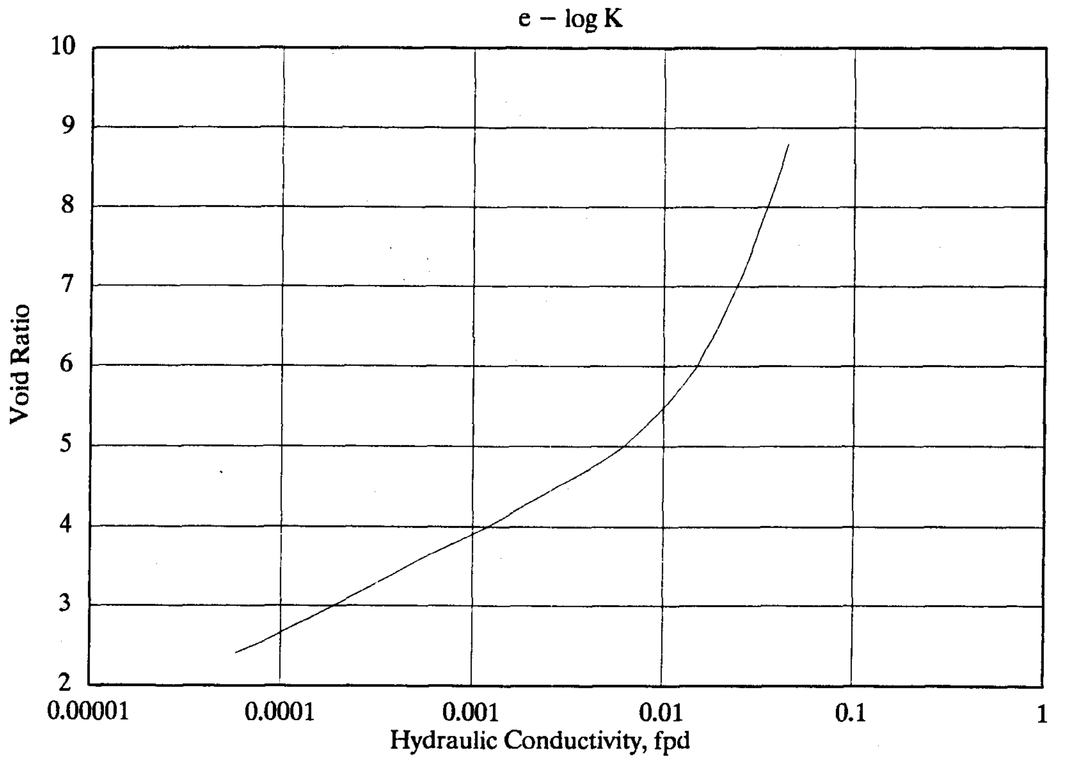


Figure 44. Void ratio-permeability relationship for NWS Yorktown sediment

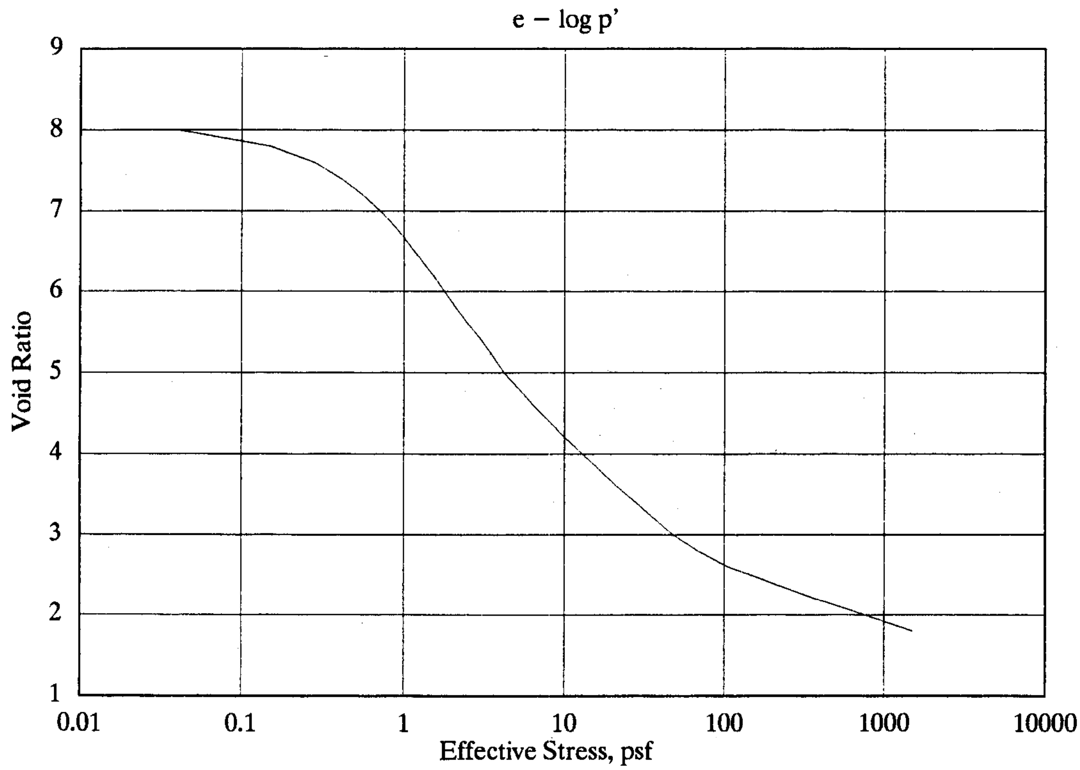


Figure 45. Void ratio-effective stress relationship for NAVPHIBASE LCREEK sediment

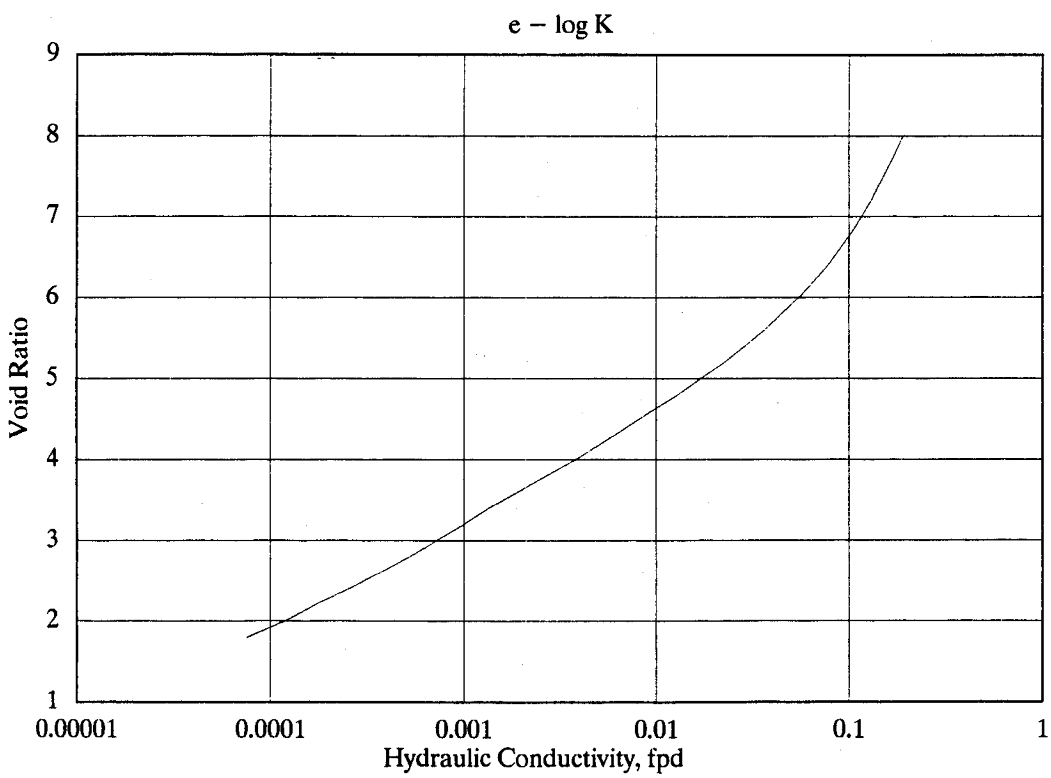


Figure 46. Void ratio-permeability relationship for NAVPHIBASE LCREEK sediment

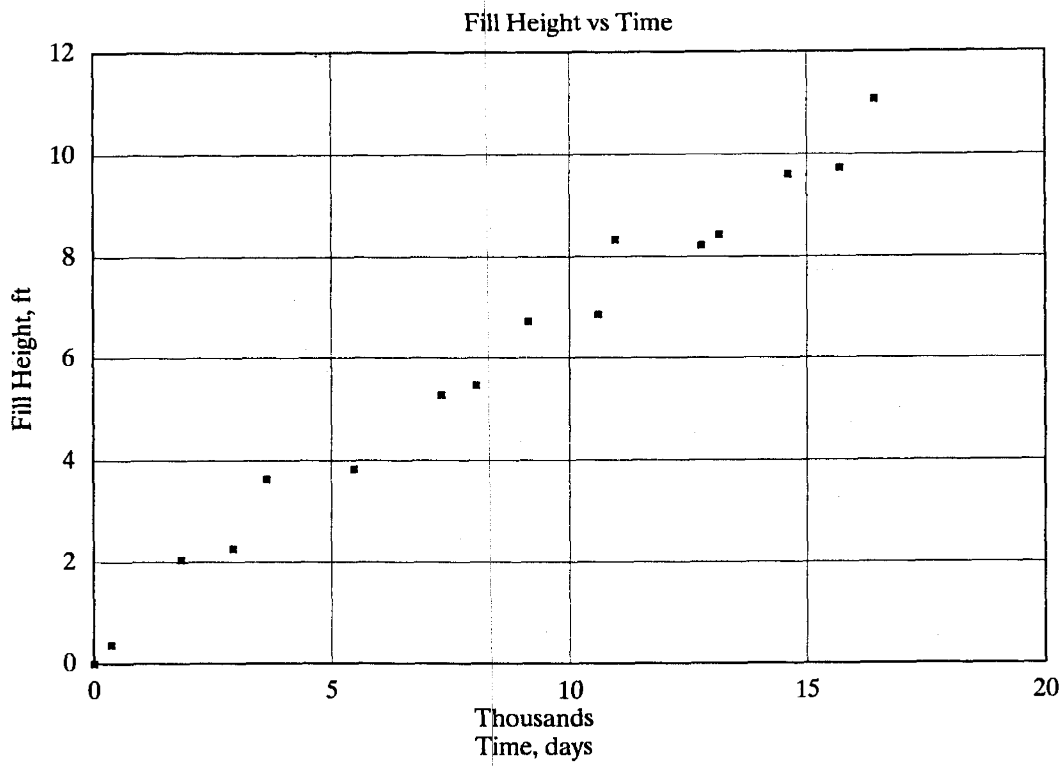


Figure 47. Fill height versus time for NWS Yorktown Forest site

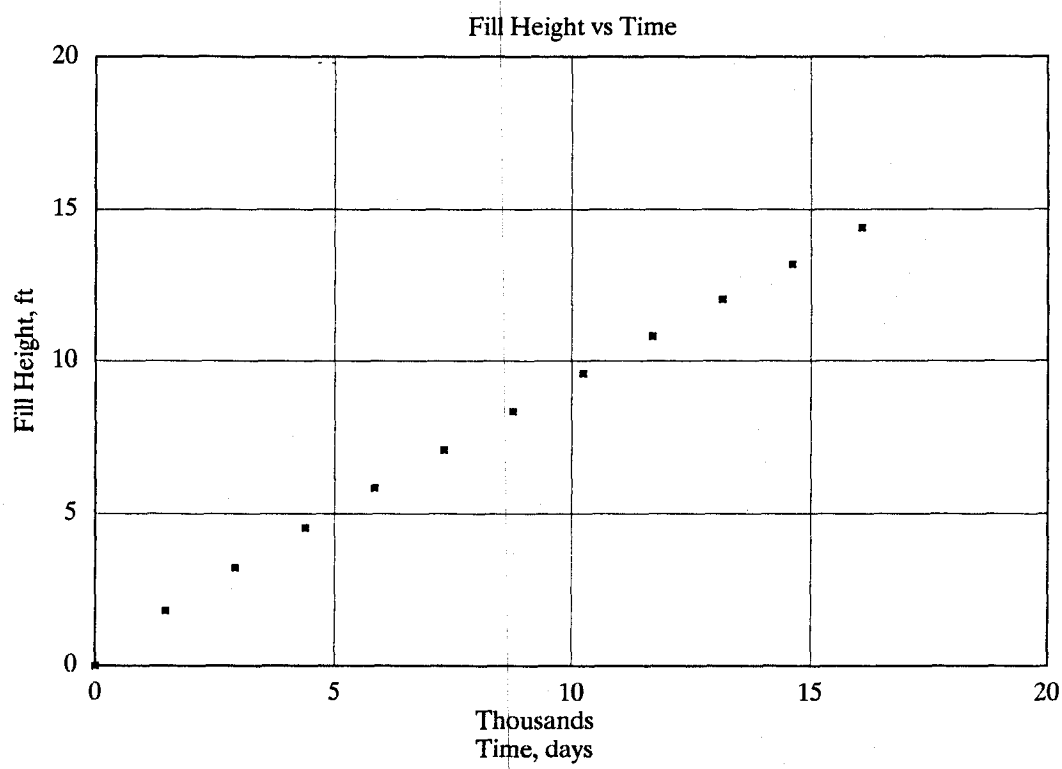


Figure 48. Fill height versus time for NAVPHIBASE LCREEK Beach Drive site

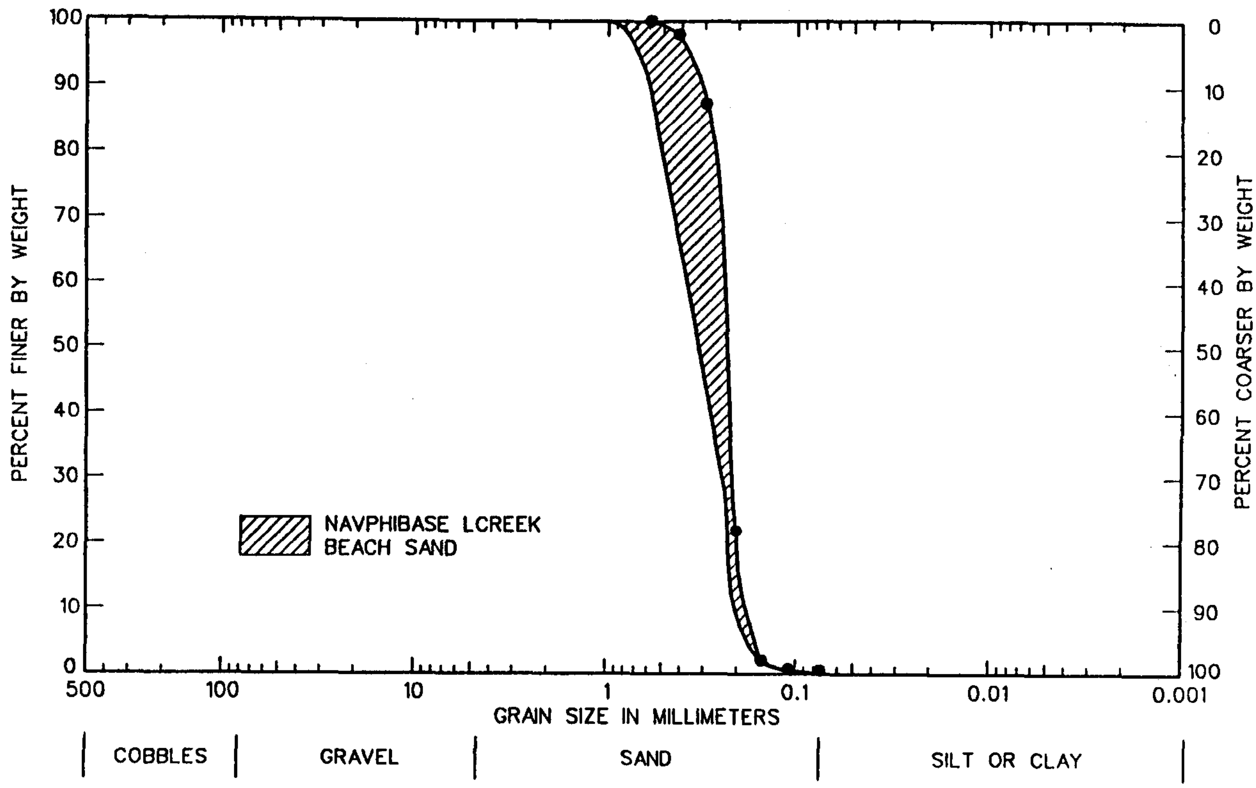


Figure 49. Grain size distribution range of existing beach sand at NAVPHIBASE LCREEK

APPENDIX A:
EQUILIBRIUM PARTITIONING ESTIMATES FOR CDF PORE WATER QUALITY

1. An assessment of the potential for movement of contaminants as leachate into groundwater below confined disposal facilities (CDFs) was made based on conservative equilibrium partitioning principles. This evaluation indicates a worst-case potential for contaminant movement into leachate.

2. For this evaluation, it is assumed that dredged material has been placed in a CDF, pore water seepage transports contaminants from the dredged material solids to foundation soils beneath the CDF, and the dredged material is anaerobic. Needs for leachate tests were evaluated by comparing estimated pore water contaminant concentrations to available drinking water limits. In the following paragraphs, the theoretical basis for estimating contaminant pore water concentrations, the information used to make the estimates, discussion of results, and recommendations for additional testing are presented.

Theory

3. Equilibrium partitioning was the theoretical basis for estimating contaminant concentrations in pore water. Application of this theory to dredged material is described by Hill, Myers, and Brannon (1988).* The equilibrium assumption is valid when the seepage velocity is slow relative to the rate at which contaminants desorb from dredged material solids. This is a realistic assumption because seepage velocities for fine-grained dredged material are usually very low due to low hydraulic conductivity. Even when pore water velocities are too high for the equilibrium assumption to be valid, estimates of pore water contaminant concentrations based on the equilibrium assumption are conservative; that is, they overestimate pore water contaminant concentrations.

4. When contaminant concentrations are low, as is the case for the sediments evaluated in this report, linear desorption can be assumed. Linear-equilibrium desorption is described by the following equation:

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* See References at the end of the main text.

$$C_s = K_d C_w \tag{1}$$

where C_s is the equilibrium contaminant concentration in the dredged material solids (mg/kg), C_w is the equilibrium contaminant concentration in the pore water (mg/ℓ), and K_d is the distribution coefficient (ℓ/kg). To calculate pore water organic contaminant concentration given a sediment contaminant concentration equation, Equation 1 is rearranged to yield

$$C_w = \frac{C_s}{K_d} \tag{2}$$

5. The distribution coefficient in Equations 1 and 2 is a contaminant- and sediment-specific constant that describes the distribution of contaminant between dredged material solids and pore water at equilibrium. For organic contaminants, K_d can be estimated by the following equation (Karickhoff 1981)

$$K_d = f_{oc} K_{oc} \tag{3}$$

where f_{oc} is the fraction organic carbon in the sediment solids and K_{oc} is the organic carbon partition coefficient. K_{oc} is a contaminant-specific constant for which there are a number of empirical relationships available for predicting K_{oc} on the basis of solubility or octanol-water partition coefficient (Lyman, Reehl, and Rosenblatt 1990).

6. The theoretical and experimental basis for estimating metal pore water concentrations is not as well developed as that for organic contaminants. The basic approach for metals is the same as the approach for organic contaminants except that Equations 1 and 2 as stated are not applicable to metals. Equations 1 and 2 are not applicable because the total metal concentration in the dredged material solids is not leachable. A significant fraction of the total metal concentration in sediments is in geochemical phases that are not mobilized by aqueous extraction (Brannon et al. 1976; Steneker, Van Der Sloot, and Das 1988).

7. Modification of equations 1 and 2 for the leachable metal concentration provides a method for estimation of pore water metal concentrations. Assuming equilibrium theory applies, the distribution of leachable metal between the solid and aqueous phases at equilibrium is given by

$$C_{s1} = K_d \, C_w \tag{4}$$

where C_{s1} is the leachable metal concentration in the dredged material solids (mg/kg). To calculate a pore water metal contaminant concentration given a sediment contaminant concentration, Equation 4 is rearranged to yield

$$C_w = \frac{C_{s1}}{K_d} \tag{5}$$

8. Empirical relationships for estimating C_{s1} and K_d for metals are not available. These parameters are sediment-specific, as well as metal-specific). They are affected by a variety of factors including oxidation-reduction potential, pH, and organic carbon, sulfur, iron, and salt contents of the sediment. For these reasons, k_d and C_{s1} are difficult to estimate a priori. Information from anaerobic sequential batch leach tests conducted on sediments similar to the sediments of interest in this study (estuarine sediments) were used to estimate a range of leachable metal concentrations and a range of distribution coefficients for metals.

<u>Calculations for organics</u>

9. Distribution coefficients for each organic contaminant were estimated with Equation 3 using values of K_{oc} as given in Mercer, Skipp, and Griffin (1990) (Table A1) and f_{oc} data provided by bulk sediment analysis (Table A2). However, K_{oc} values were not available in Mercer, Skipp, and Griffin (1990) for all organic contaminants of interest. K_{oc} values not given in Mercer, Skipp, and Griffin (1990) were estimated using empirical relationships from the literature. For endosulfan sulfate and endrin, K_{oc} values were estimated using Equation 6 (Chiou, Porter, and Schmeddling 1983)

$$\log K_{ow} = 0.904 \log K_{ow} - 0.779 \tag{6}$$

where K_{ow} is the octanol-water partition coefficient. K_{oc} for Aroclor 1260 was estimated using Karickhoff's (1981) equation

$$K_{oc} = 0.411\ K_{ow} \tag{7}$$

K_{ow} values from Mercer, Skipp, and Griffin (1990) were used in Equations 6 and 7. K_{oc} for endrin aldehyde was estimated using Equation 8 (Chiou, Porter, and Schmeddling 1983)

$$\log K_{oc} = -\ 0.729 \log S + 0.001 \tag{8}$$

where S is the solubility in water (moles/ℓ). Solubility of endrin aldehyde was estimated using the method of Irmann (Lyman, Reehl, and Rosenblatt 1990).

10. Values of K_d (calculated by Equation 3) and estimated pore water concentrations (calculated by Equation 2) for each organic contaminant are listed in Tables A3, A4, and A5 for the NWS, CA, and LC sediments, respectively. Available drinking water limits are also listed in Tables A3, A4, and A5 for comparison. Tables A3, A4, and A5 were prepared using average sediment contaminant concentrations (Table A2). The averaging used to obtain the bulk sediment concentrations in Table A2 did not include values below the detection limit. The data in Table A2, therefore, overestimate true averages for data sets which include values below the detection limit. Although this method of averaging is conservative, it provides a margin of safety for estimations involving sparse data sets.

11. No partition coefficient data were available for cyanide. Cyanide can exist as the cyanide ion, as simple cyanide compounds, and as complex cyanides. Many simple metal cyanides have low solubilities, but they form a variety of highly soluble, complex metal cyanides in the presence of alkali cyanides. Pore water cyanide concentrations were not estimated because the total cyanide analysis available does not provide sufficient basis for estimating pore water concentration.

Calculations for metals

12. Estimated pore water metal concentrations are shown in Figures A1 through A11. Drinking water limits for metals where available are also shown for comparison. Ranges of estimated metal pore water concentrations are presented instead of single estimates because many factors influence C_{s1} and K_d that cannot be accounted for without laboratory testing. The concentration envelopes presented in Figures A1 through A11 are based on best estimates of values that C_{s1} and K_d might take on for the Navy sediments. The concentration envelopes are conservative; that is, they tend to overestimate metal pore water concentrations. Pore water metal concentrations may be lower than indicated in Figures A1 through A11, but the $K_d = 3\ \ell/kg$ line represents maximum values that can reasonably be expected. The concentration envelopes are conservative since, as discussed in the following paragraphs, the range in leachable fraction encompasses the upper end of the available data estuarine sediments and the range in distribution coefficients encompasses the lower end of the available data on estuarine sediments.

13. Data from Brannon et al. (1976), Steneker, Van Der Sloot, and Das (1988), Myers and Brannon (1988), and Palermo et al. (1989) on leachable metal fractions in five estuarine sediments are presented in Table A6. As indicated in Table A6, the approximate percentage of the total cadmium, chromium, copper, nickel, and lead in the sediments investigated in these studies that was leachable ranged from 0.5 to 5.0. The approximate percentage of the total arsenic in the sediments investigated in these studies that was leachable ranged from 0.5 to 10.0. The approximate percentage of the total zinc investigated in these studies that was leachable ranged from 1 to 15. The above ranges in leachable metal fractions were used to estimate ranges of C_{s1} for each metal in the NWS, CA, and LC sediments. The leachable concentration is given by multiplying the total metal concentration by the percent leachable divided by 100.

14. Data on leachable fractions for beryllium, mercury, silver, and thallium were not available. Mercury was investigated by Palermo et al. (1989), but detectable amounts did not leach in sequential batch tests. Other studies have also shown that very little of the bulk mercury concentration in sediments is mobile (Brannon, Plumb, and Smith 1980). The leachable fractions for beryllium, mercury, silver, and thallium were estimated to range from 0.1 to 1.0 percent. This estimate is based primarily on judgement.

15. Distribution coefficients are also needed to estimate pore water metal concentrations. Conservative estimates are obtained when high values of K_d are avoided; that is, the lower end of the range in expected K_d values is used. Anaerobic sequential batch leach data from Palermo et al. (1989) and Myers and Brannon (1988) were re-analyzed and distribution coefficients corresponding to maximum metal concentrations in leachate samples were calculated. K_d values ranged from 5 to 90 ℓ/kg, depending on the metal and the sediment. The range of K_d values selected for conservative estimation of metal pore water concentrations was $3 \leq K_d \leq 10$ ℓ/kg. This range of K_d values, the range in the percent leachable discussed previously, and Equation 5 were used to calculate the concentration envelopes in Figures A1 through A11.

<u>Discussion of results</u>

16. As indicated in Tables A3, A4, and A5, estimated pore water concentrations for organic contaminants were below drinking water limits. Drinking water criteria are not available for most organic contaminants. The estimated pore water concentrations for organic contaminants were also below acute fresh and marine water quality criteria (US Environmental Protection Agency 1986).

17. Pore water concentrations for cyanide were not estimated for the reasons previously discussed. Only one sediment sample, LC-9, contained cyanide (0.873 mg/kg). The cyanide in this sample could be a statistical outlier caused by errors in sampling, preservation, and/or analysis.

18. Estimated pore water metal concentrations vary depending on distribution coefficients and percentage of the total metal concentration that is leachable. As indicated in Figures A1 through A11, pore water concentrations for some metals could exceed drinking water criteria. The estimated range in pore water concentrations for cadmium, mercury, and silver did not exceed drinking water limits for any of the sediments. Copper was below the drinking water limit in all cases except one, and in this instance the estimated pore water concentration of copper was above the drinking water limit by a factor of only 1.2. For the CA and NWS sediments, zinc was below the drinking water limit for leachable fractions less than 0.1 (10 percent of total zinc concentration). If the leachable fraction of zinc in the CA and NWS sediments is greater than 0.1, pore water zinc concentrations are not expected to exceed the drinking water limit by a factor of more than 1.5. For the LC sediment, estimated zinc pore water concentrations exceeded the drinking water limit for some K_d values when leachable fractions were greater than 0.06 (6 percent of the total zinc concentration). The maximum estimated zinc pore water

concentration for the LC sediment exceeded the drinking water limit by a factor of 2.5. Arsenic was below the drinking water limit for leachable fractions less than 0.04 (4 percent of the total arsenic concentration). If the leachable fraction of arsenic is greater than 0.04, pore water arsenic concentrations could exceed the drinking water limit by factors ranging from 2.8 to 3.4, depending on the sediment. Estimated chromium and lead concentrations tended to exceed the drinking water limit for all three sediments. If the leachable fraction of chromium is greater than 0.03, pore water chromium concentrations could exceed the drinking water limit by factors of 11 to 19. Pore water lead concentrations could exceed the drinking water limit by factors ranging from 6 to 19 depending on the sediment.

19. Estimates of pore water quality are just part of the information needed to evaluate leachate impacts on groundwater resources. The hydraulic conductivity of the dredged material and foundation soils significantly affects seepage rate. The sorption properties of foundation soils also significantly affect the transport of contaminants to groundwater. Most foundation soils can adsorb metals and attenuate their movement. In addition, dilution by groundwater and sorption by aquifer materials can lower contaminant concentrations at offsite monitoring wells to below drinking water limits. When seepage is low and soil sorption is high, impacts on groundwater can be negligible.

Need for additional leach tests

20. Because of the above considerations, it should be emphasized that estimates of pore water concentrations do not necessarily indicate that groundwater leachate would be an environmental problem, only that additional tests may be warranted. The following recommendations are made regarding additional leach tests:

a. Because the estimated pore water concentrations for organic contaminants were below available drinking water limits, laboratory leach testing for organic contaminants is not recommended.

b. Since only one sediment sample (LC-9) contained cyanide, no leach tests for cyanide are recommended.

c. No leach testing is recommended for cadmium, mercury, silver, and copper because the estimated pore water concentrations were below, less than, or approximately equal to drinking water limits.

d. Although arsenic and zinc pore water concentrations could exceed drinking water limits, no leach testing for arsenic and zinc are recommended because the maximum exceedence for zinc was only 1.5 times the drinking water limit and the maximum exceedence for arsenic was only 3.4 times the drinking water limit. Sorption and dilution in foundation soils would be expected to reduce arsenic and zinc concentrations to below drinking water limits.

e. Because estimated lead and chromium pore water concentrations generally exceeded drinking water limits and maximum exceedences for these metals were 19 times the drinking water limits, leach tests for lead and chromium may be needed, to provide data for predicting pore water concentrations for these metals for specific permit applications in the future. The need for testing would depend on the groundwater resources at the CDF under consideration and the lead and chromium concentrations of the sediments to be dredged.

f. If testing is required, anaerobic sequential batch leach tests described in Myers and Brannon (1988) are recommended. Tests to determine the sorption properties and hydraulic conductivity of foundation soils at candidate sites should also be considered.

Table A1

K_{oc} Values for Organic Contaminants*

Organic Contaminant	K_{oc} (ℓ/kg)
p,p-DDD	7.7 E+05
p,p-DDE	4.4 E+06
p,p-DDT	2.43 E+05
Heptachlor	12,000
Dieldrin	1,700
Endosulfan sulfate**	338.5
Endrin**	11,142
Endrin Aldehyde†	2 E+06
Heptachlor Epoxide	220
Methoxychlor	80,000
Fluoranthene	38,000
Pyrene	38,000
Chrysene	2 E+05
Bis(2-Ethylhexyl)Phthalate	5,900
Benzo(b)Fluoranthene	5.5 E+05
Aroclor-1254	42,500
Aroclor-1260††	5.67 E+06

* From Mercer, Skipp, and Griffin (1990).

** Estimated with Equation 6 and K_{ow} data from Mercer, Skipp, and Griffin (1990).

† Estimated with Equation 8.

†† Estimated with Equation 7 and K_{ow} data from Mercer, Skipp, and Griffin (1990).

Table A2

Average* Bulk Sediment Contaminant Concentrations (mg/kg)**

Chemical	Sediment NWS	Sediment CA	Sediment LC
p,p-DDD	0.0004	0.0026	0.0030
p,p-DDE	0.0022	0.0012	0.0028
p,p-DDT	0.0012	0.0022	0.0025
Heptachlor	0.0022	0.0020	0.0011
Dieldrin	0.0007	††	0.0012
Endosulfan sulfate	0.0014	0.0012	0.0007
Endrin	0.0003	††	0.002
Endrin Aldehyde	0.0011	††	††
Heptachlor Epoxide	0.0007	††	††
Methoxychlor	0.0017	††	0.0053
Fluoranthene	††	1.2	1.04
Pyrene	††	†	1.4
Chrysene	††	†	0.94
B2EPH†	††	†	0.53
Benzo(b)Fluoranthene	††	†	0.78
Aroclor-1254	††	†	0.005
Aroclor-1260	††	†	0.07
Cyanide	††	†	0.873
Arsenic	4.2	4.8	4.0
Berillium	1.01	1.7	0.88
Cadmium	0.15	0.13	0.55
Chromium	56.0	56.20	32.6
Copper	28.0	28.4	72.4
Lead	19.7	21.0	57.1
Mercury	††	††	0.642
Nickel	29.8	30.6	17.2
Silver	0.14	0.11	0.36
Thallium	0.30	0.25	0.34
Zinc	135	144	245
Organic Carbon (g/g)	0.0724	0.0298	0.0188

* Averages do not include below detection limit values.

** Except as noted.

† B2EPH = Bis(2-Ethylhexyl)Phthalate.

†† All samples were below the detection limit.

Table A3

Distribution Coefficients, Estimated Pore Water Concentrations, and Drinking Water Limits for Organic Contaminants in NWS Sediment

Organic Contaminant	Distribution Coefficient (ℓ/kg)	Estimated Pore Water Concentration (ug/ℓ)	Drinking* Water Limits (ug/ℓ)
p,p-DDD	55,770	7.2 E-06	--
p,p-DDE	3.2 E+05	6.9 E-06	--
p,p-DDT	17,600	0.0001	--
Heptachlor	869	0.0025	--
Dieldrin	123	0.0057	--
Endosulfan sulfate	24.5	0.0591	--
Endrin	807	0.0004	0.2
Endrin Aldehyde	1.4 E+05	7.9 E-06	--
Heptachlor Epoxide	15.9	0.0439	--
Methoxychlor	5,794	0.0003	100
Fluoranthene	2,752	**	--
Pyrene	2,752	**	--
Chrysene	14,485	**	--
B2EPH†	427	**	--
Benzo(b)Fluoranthene	39,835	**	--
Aroclor-1254	3,078	**	--
Aroclor-1260	4.1 E+05	**	--

* USEPA (1986).
** Not present in sediment.
† B2EPH: Bis(2-Ethylhexyl)Phthalate.

Table A4

Distribution Coefficients, Estimated Pore Water Concentrations, and Drinking Water Limits for Organic Contaminants in CA Sediment

Organic Contaminant	Distribution Coefficient (ℓ/kg)	Pore Water Concentration (ug/ℓ)	Drinking* Water Limits (ug/ℓ)
p,p-DDD	55,696	4.6 E-05	--
p,p-DDE	3.2 E+05	3.9 E-06	--
p,p-DDT	17,577	0.0001	--
Heptachlor	868	0.0022	--
Dieldrin	122	**	--
Endosulfan sulfate	24.5	0.0490	--
Endrin	805	**	0.2
Endrin Aldehyde	59,600	**	--
Heptachlor Epoxide	15.9	**	--
Methoxychlor	5,786	**	100
Fluoranthene	2,748	0.4366	--
Pyrene	2,748	**	--
Chrysene	14,466	**	--
B2EPH†	426	**	--
Benzo(b)Fluoranthene	39,783	**	--
Aroclor-1254	3,074	**	--
Aroclor-1260	4.1 E+05	**	--

* USEPA (1986).
** Not present in sediment.
† B2EPH - Bis(2-Ethylhexyl)Phthalate.

Table A5

Distribution Coefficients, Estimated Pore Water Concentrations, and Drinking Water Limits for Organic Contaminants in LC Sediment

Organic Contaminant	Distribution Coefficient (ℓ/kg)	Pore Water Concentration (ug/ℓ)	Water* Quality Criteria (ug/ℓ)
p,p-DDD	26,110	0.0001	--
p,p-DDE	1.5 E+05	1.8 E-05	--
p,p-DDT	823	0.0003	--
Heptachlor	407	0.0029	--
Dieldrin	57.6	0.0191	--
Endosulfan sulfate	11.5	0.0610	--
Endrin	378	0.0053	0.2
Endrin Aldehyde	37,600	--	--
Heptachlor Epoxide	7.46	**	--
Methoxychlor	2,713	0.0020	100
Fluoranthene	1,288	0.8071	--
Pyrene	1,288	1.0865	--
Chrysene	6,782	0.1386	--
B2EPH†	200	2.6492	--
Benzo(b)Fluoranthene	18,650	0.0418	--
Aroclor-1254	1,441	0.0035	--
Aroclor-1260	1.9 E+05	0.0004	--

* USEPA (1986).
** Not present in sediment.
† B2EPH = Bis(2-Ethylhexyl)Phthalate.

Table A6

Leachable Metals in Selected Estuarine Sediments

	Percent Leachable				
Metal	Mobile* Bay	Bridgeport* Harbor	Everett** Bay	New Bedford† Harbor	Rotterdam†† Harbor
Arsenic	3.12	1.66	7.33	1.73	‡
Cadmium	0.60	4.32	3.33	0.68	1.82
Chromium	‡	‡	1.11	0.69	‡
Copper	0.74	0.008	2.32	1.31	2.27
Nickel	2.16	1.66	3.74	0.98	‡
Lead	‡	‡	2.50	0.25	3.18
Zinc	2.22	14.16	2.02	0.97	2.50

* Sum of interstitial, exchangeable, and moderately reducible phases, from Brannon et al. (1976).

** Total extracted in anaerobic sequential batch leach test, from Palermo et al. (1989).

† Total extracted in anaerobic sequential batch leach test, from Myers and Brannon (1988).

†† Total extracted in anaerobic sequential batch leach test, from Steneker, Van Der Sloot, and Das (1988).

‡ No data.

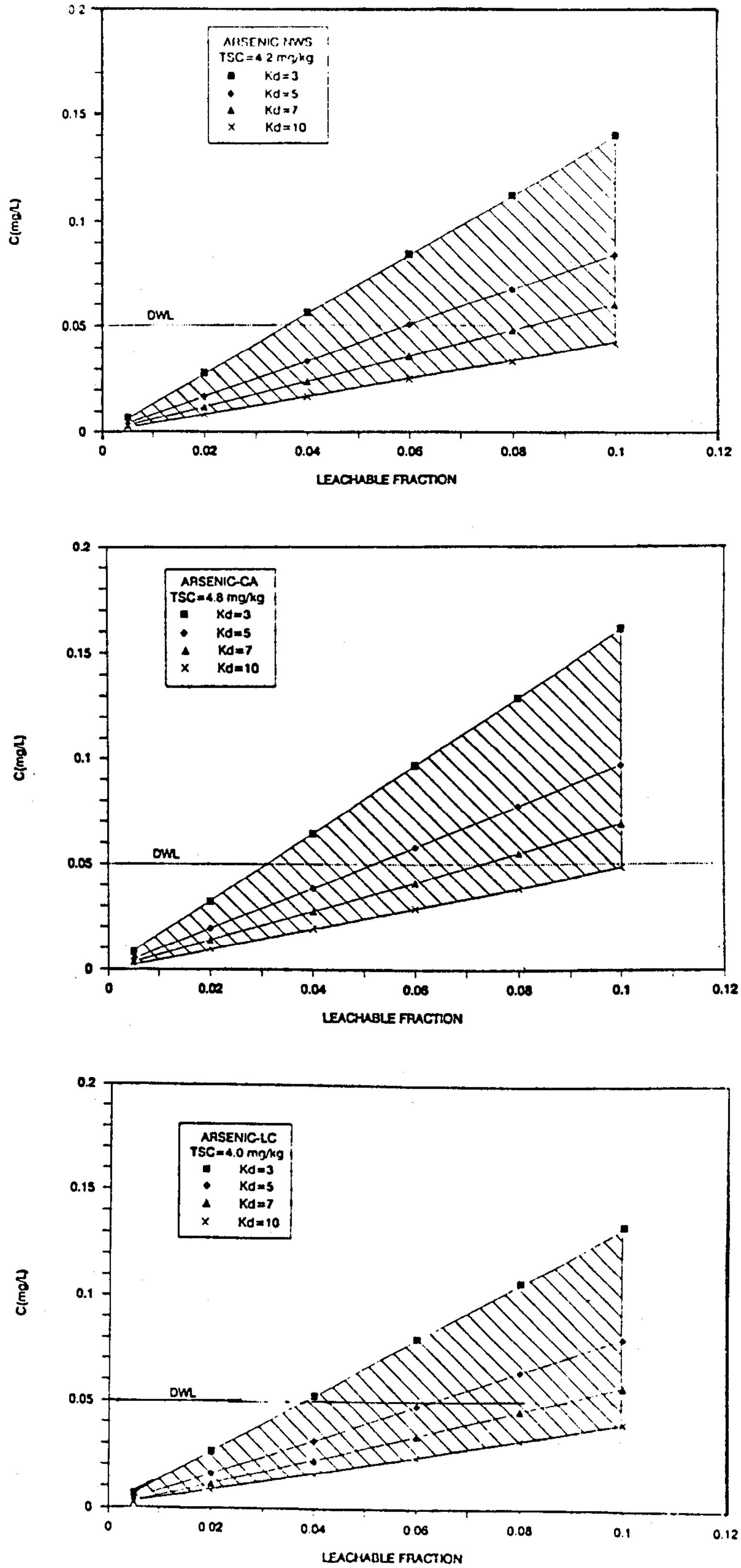

Figure A1. Estimated arsenic pore water concentrations in NWS, CA, and LC sediments as a function of K_d and leachable fraction (TSC = total sediment concentration, DWL = drinking water limit)

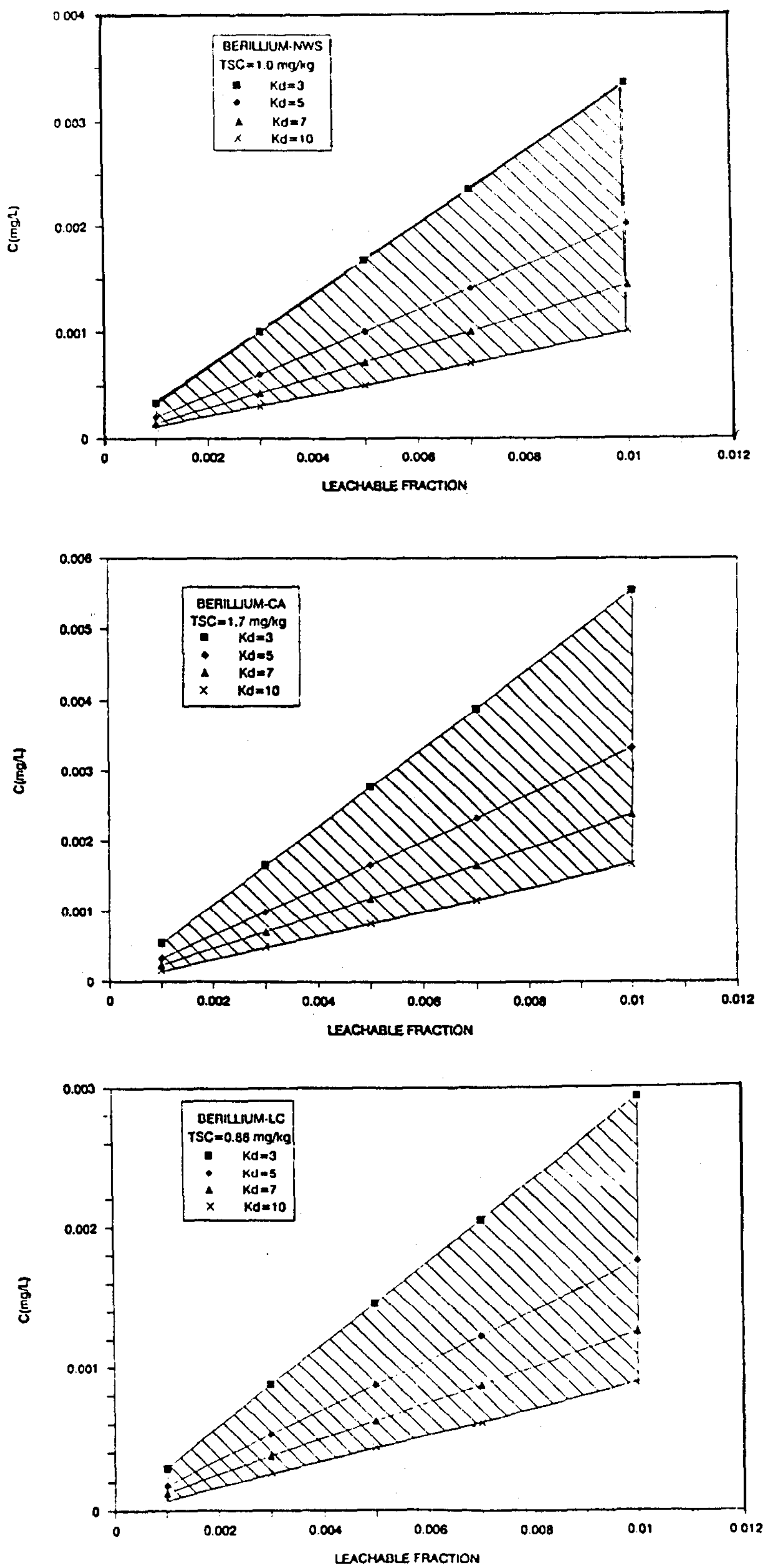

Figure A2. Estimated beryllium pore water concentrations in NWS, CA, and LC sediments as a function of K_d and leachable fraction (TSC is the total sediment concentration)

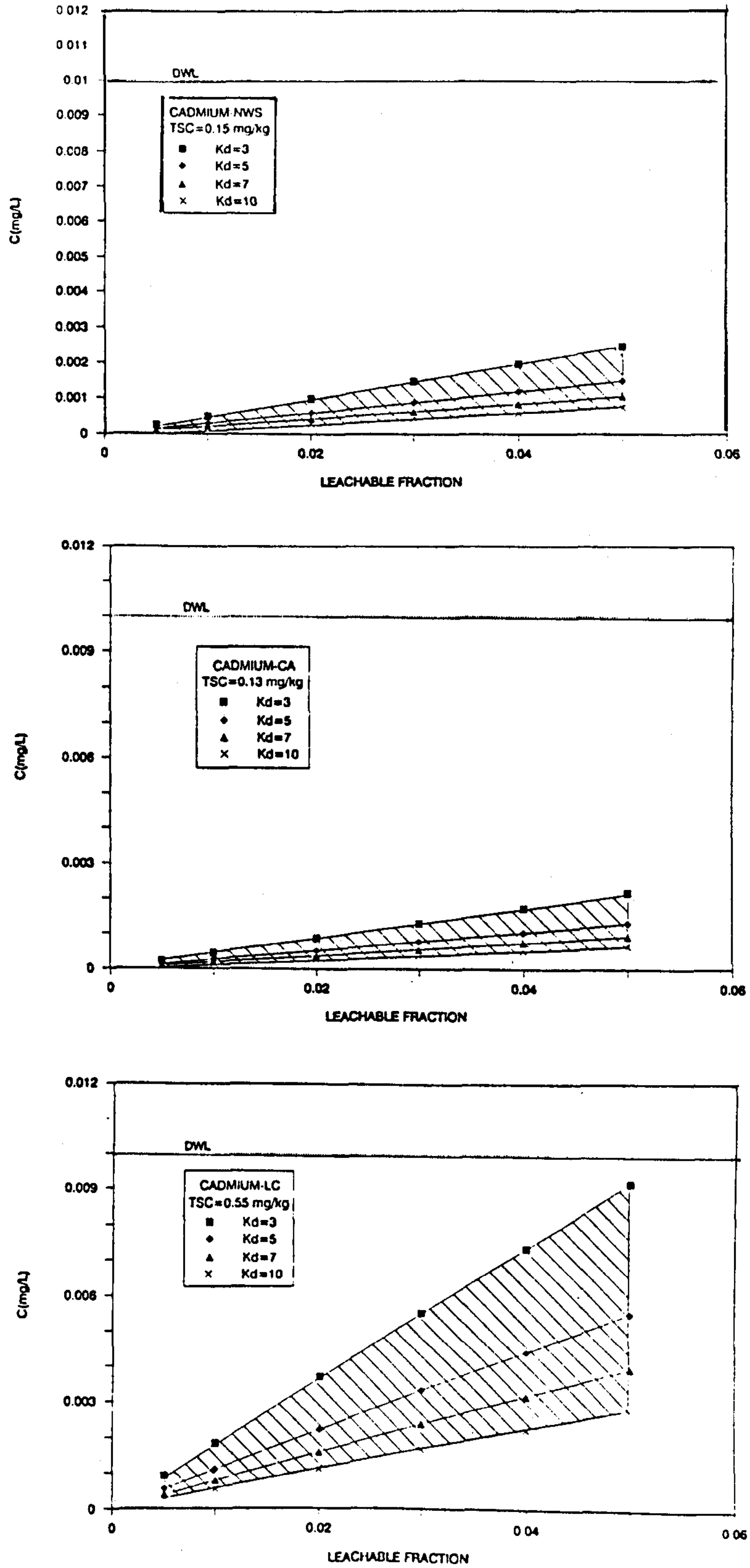

Figure A3. Estimated cadmium pore water concentrations in NWS, CA, and LC sediments as a function of K_d and leachable fraction (TSC = total sediment concentrations, DWL = drinking water limit)

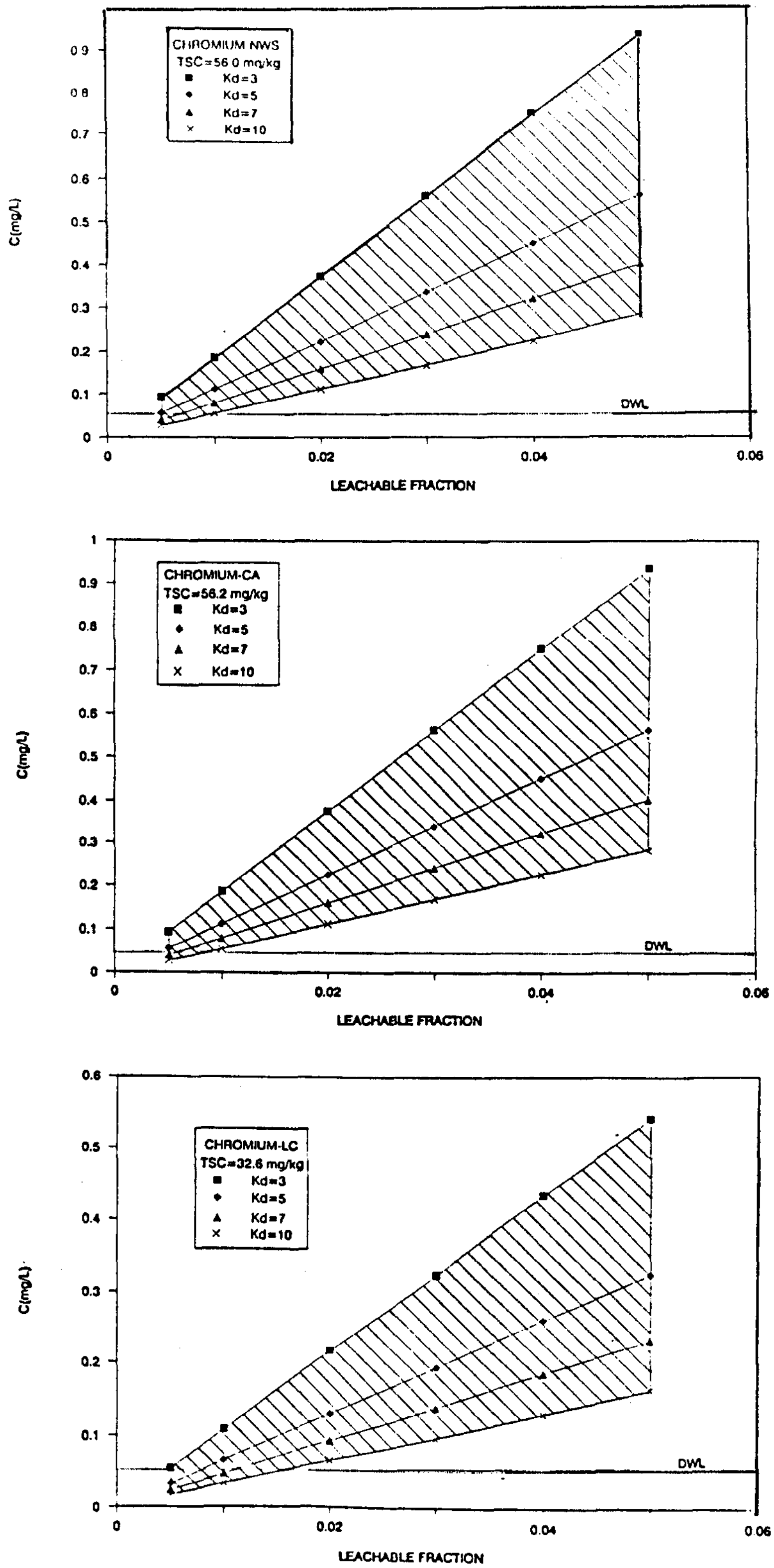

Figure A4. Estimated chromium pore water concentrations in NWS, CA, and LC sediments as a function of K_d and leachable fraction (TSC = total sediment concentration, DWL = drinking water limit)

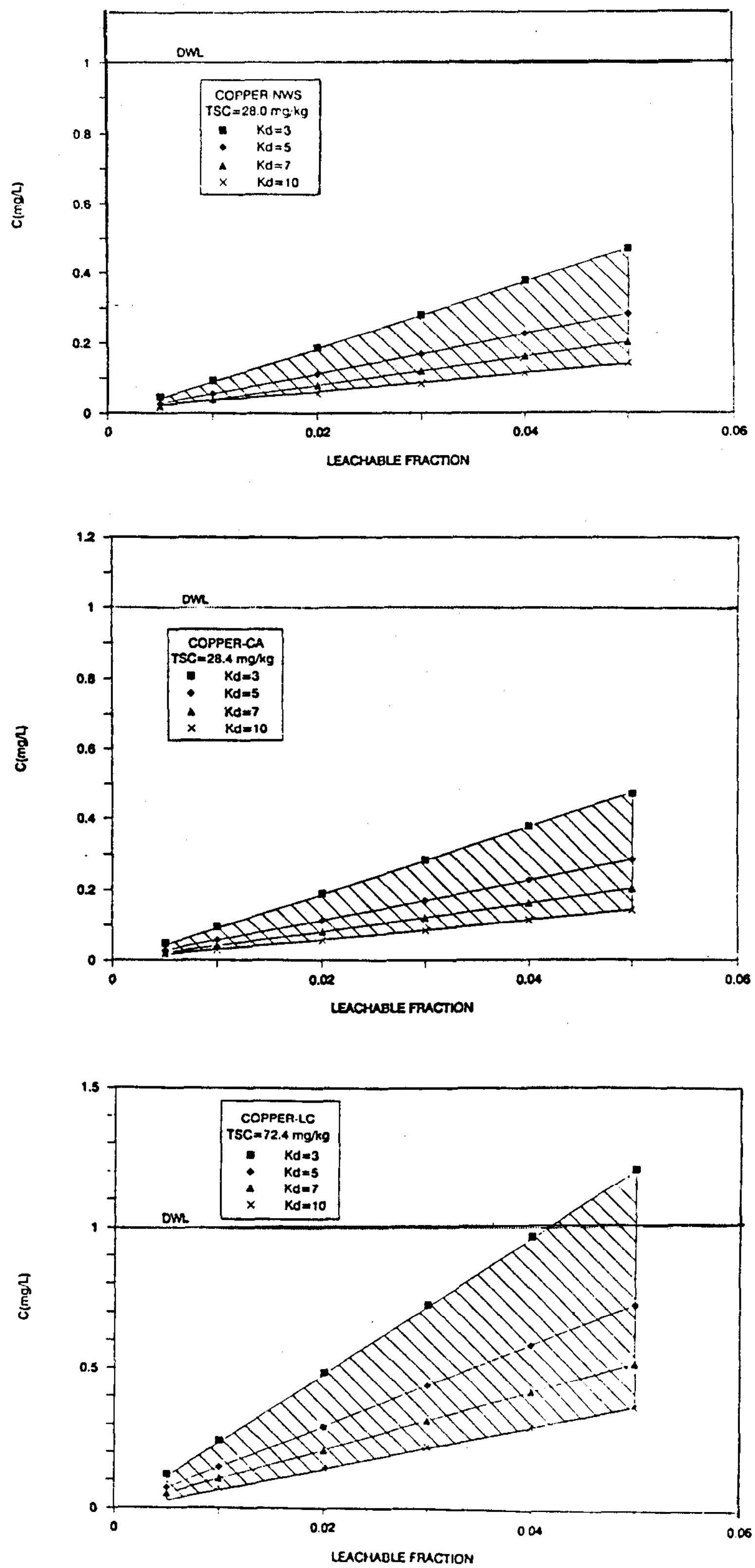

Figure A5. Estimated copper pore water concentrations in NWS, CA, and LC sediments as a function of K_d and leachable fraction (TSC = total sediment concentration, DWL = drinking water limit)

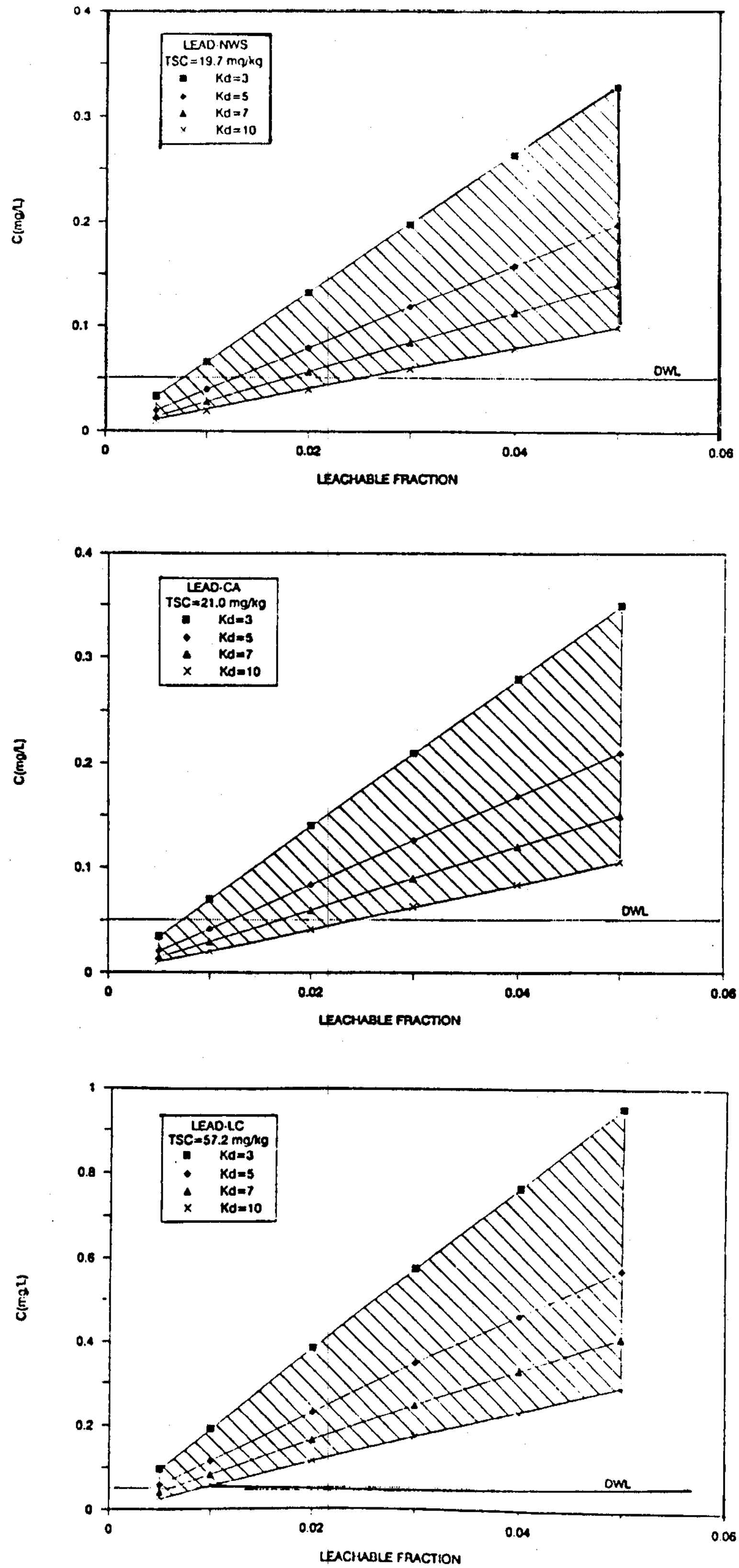

Figure A6. Estimated lead pore water concentrations in NWS, CA, and LC sediments as a function of K_d and leachable fraction (TSC = total sediment concentrations, DWL = drinking water limit)

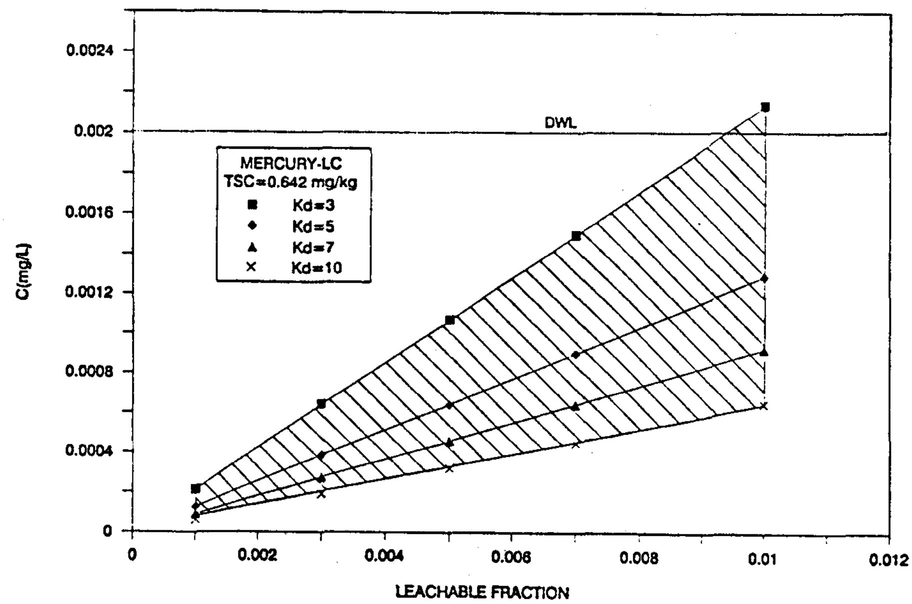

Figure A7. Estimated mercury pore water concentrations in LC sediment as a function of K_d and leachable fraction (Hg was not present in NWS and CA sediments, TSC = total sediment concentration, DWL = drinking water limit)

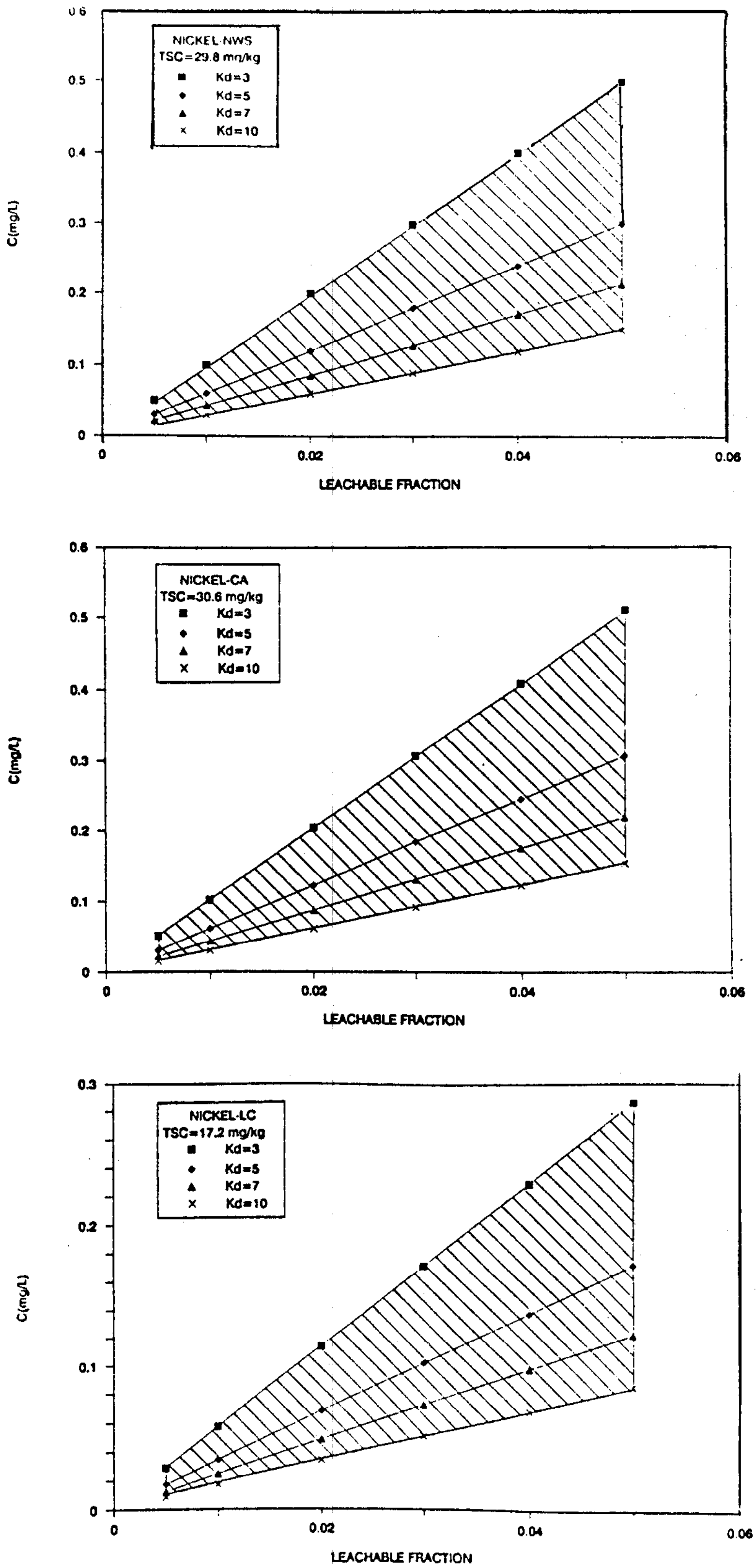

Figure A8. Estimated nickel pore water concentrations in NWS, CA, and LC sediments as a function of K_d and leachable fraction (TSC = total sediment concentration)

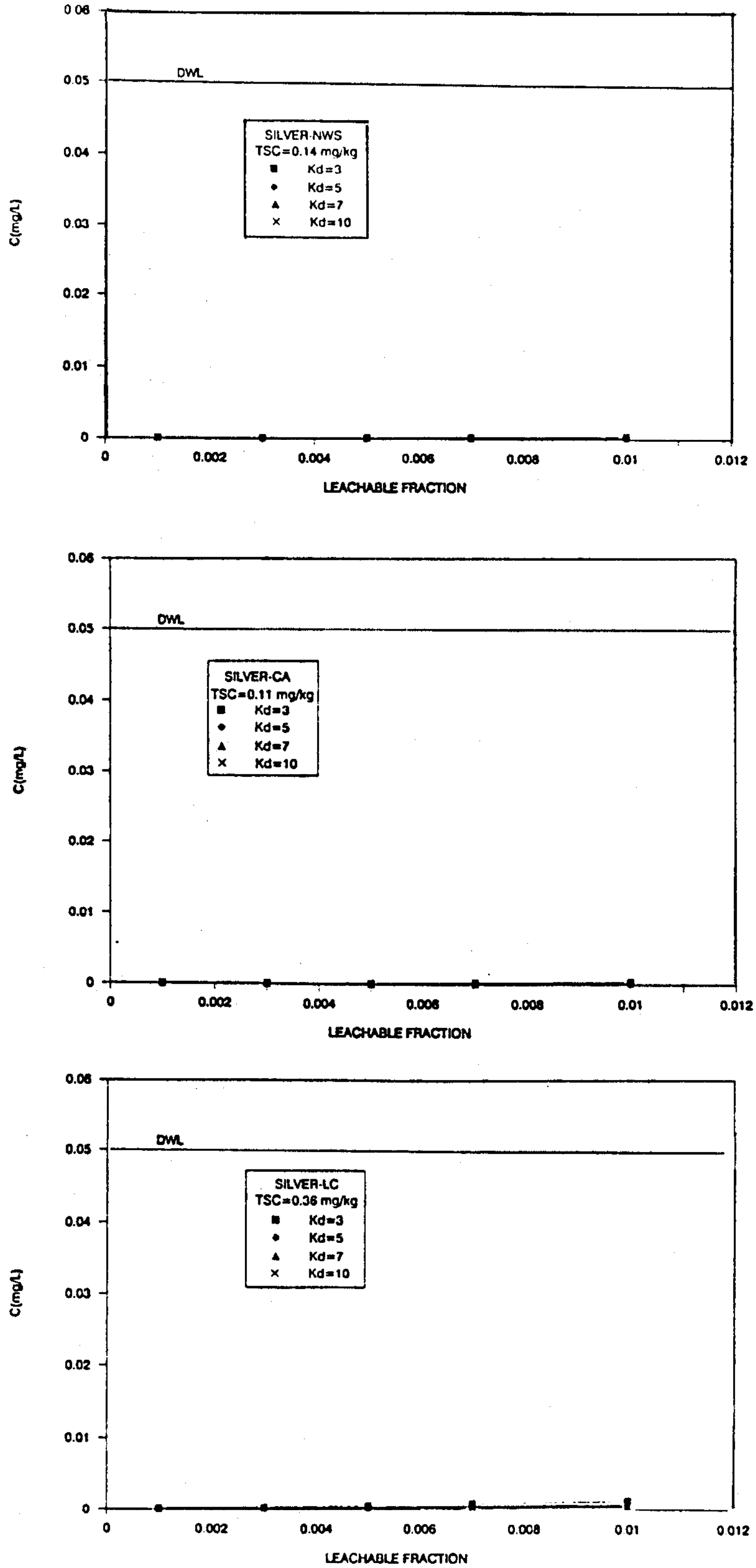

Figure A9. Estimated silver pore water concentrations in NWS, CA, and LC sediments as a function of K_d and leachable fraction (TSC = total sediment concentration, DWL = drinking water limit)

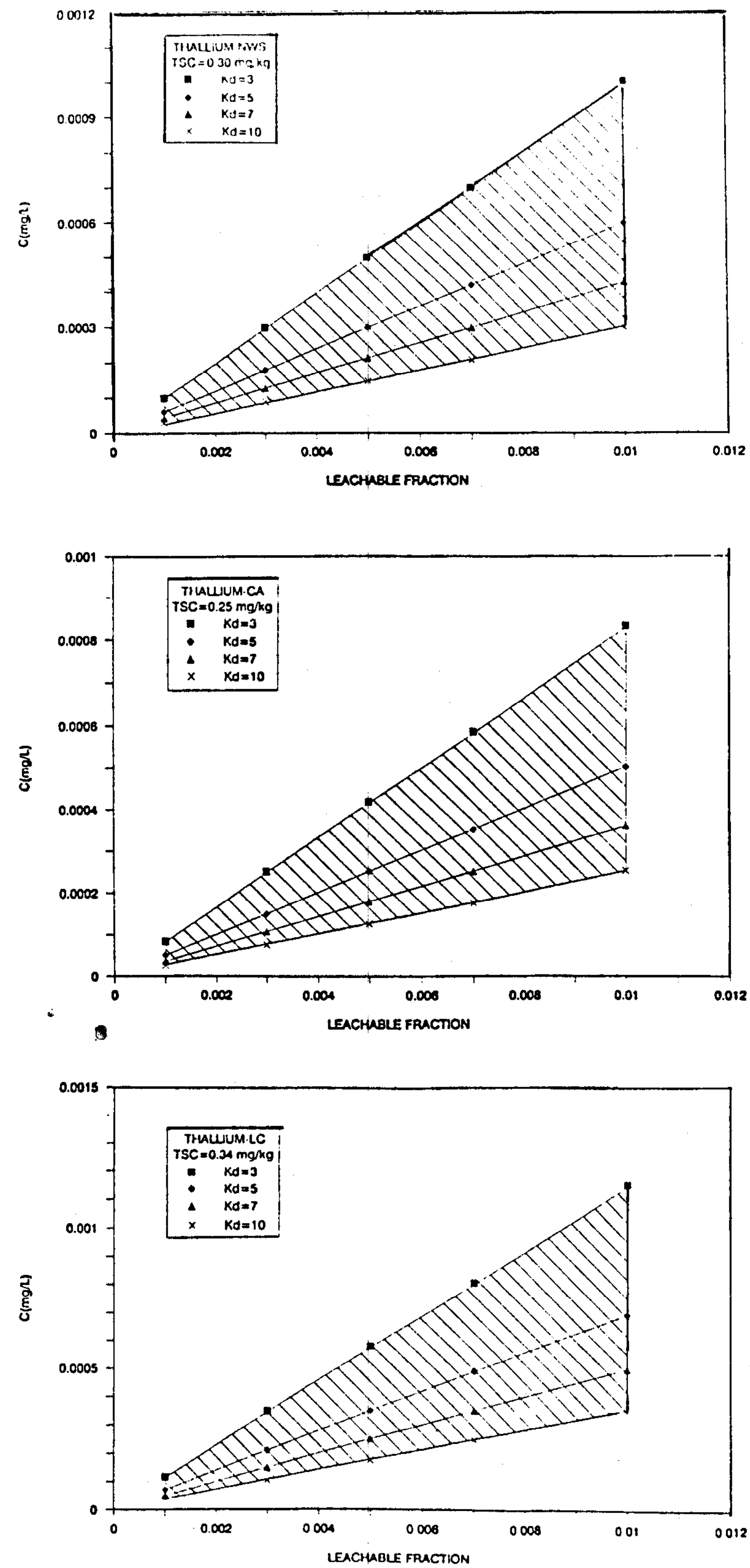

Figure A10. Estimated thallium pore water concentrations in NWS, CA, and LC sediments as a function of K_d and leachable fraction (TSC = total sediment concentration)

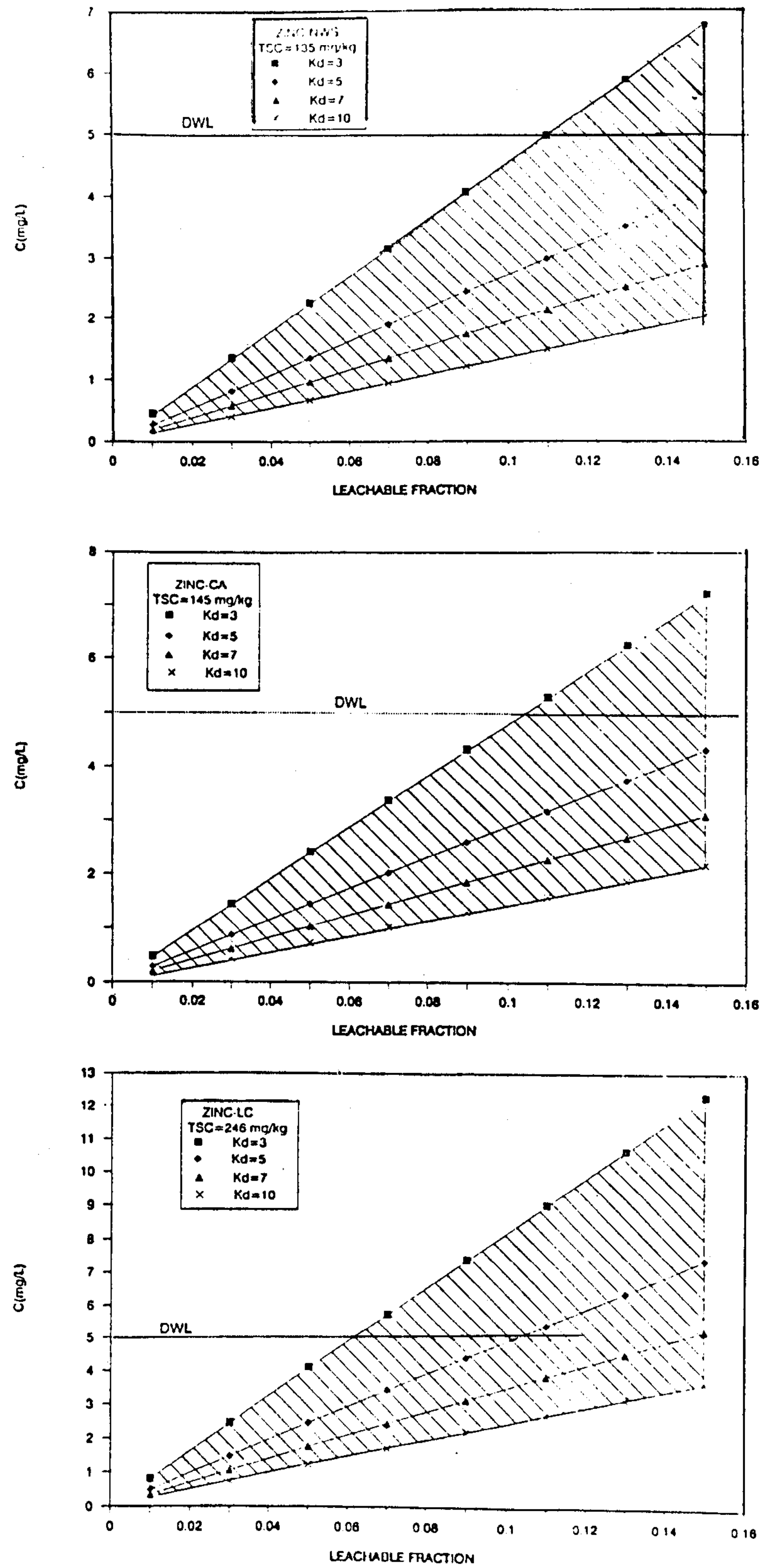

Figure A11. Estimated zinc pore water concentrations in NWS, CA, and LC sediments as a function of K_d and leachable fraction (TSC = total sediment concentration, DWL = drinking water limit)

APPENDIX B

GLOSSARY

Definitions of terms as they are used in this document are given below.

Aquatic Environment - The geochemical environment in which dredged material is submerged under water and remains water-saturated after disposal is completed.

Aquatic Ecosystem - Bodies of water, including wetlands, that serve as the habitat for interrelated and interacting communities and populations of plants and animals.

Baseline - Belt of the seas measured from the line of ordinary low water along that portion of the coast that is in direct contact with the open sea and the line marking the seaward limit of inland waters (See Figure 1 in the main text).

Beneficial Uses - Placement or use of dredged material for some productive purpose. Beneficial uses may involve either the dredged material or the placement site as the integral component of the beneficial use.

Bioaccumulation - The accumulation of contaminants in the tissues of organisms through any route, including respiration, ingestion, or direct contact with contaminated water, sediment, or dredged material.

Biological Monitoring - Systematic determination of the effects on aquatic life, including accumulation of pollutants in tissue, in receiving waters as a result of the discharge of pollutants (a) by techniques and procedures, including sampling of organisms representative of appropriate levels of the food chain appropriate to the volume and the physical, chemical, and biological characteristics of the effluent, and (b) at appropriate frequencies and locations.

Coastal Zone - Includes coastal waters and the adjacent shorelands designated by a State as being included within its approved coastal zone management program under the Coastal Zone Management Act (CZMA 1972). The coastal zone may include open waters, estuaries, bays, inlets, lagoons, marshes, swamps, mangroves, beaches, dunes, bluffs, and coastal uplands. Coastal-zone uses can include housing, recreation, wildlife habitat, resource extraction, fishing, aquaculture, transportation, energy generation, commercial development, and waste disposal (NOAA 1988).

Confined Disposal - A disposal method that isolates the dredged material from the environment. Confined disposal includes capping and contained aquatic disposal at open-water sites and placement of dredged material within diked intertidal or upland confined disposal facilities via pipeline or other means.

Confined Disposal Facility (CDF) - A confined disposal facility (CDF) is a diked area used to contain dredged material. The terms confined disposal facility, dredged material containment area, diked disposal facility, and confined disposal area are used interchangeably in the literature.

Contaminant - A chemical or biological substance in a form that can be incorporated into, onto, or be ingested by and that harms aquatic organisms, consumers of aquatic organisms, or users of the aquatic environment.

Contaminated Sediment or Contaminant Dredged Material - Contaminated sediments or contaminated dredged materials are defined as those that have been demonstrated to cause an unacceptable adverse effect on human health or the environment.

Control Measure - See Management Action.

Disposal site or area - A precise geographical area within which disposal of dredged material occurs.

Dredged Material - Material excavated from waters of the United States or ocean waters. The term dredged material refers to material which has been dredged from a water body, while the term sediment refers to material in a water body prior to the dredging process.

Dredged Material Discharge - The term dredged material discharge as used in this document means any addition of dredged material into waters of the United States or ocean waters. The term includes open water discharges; discharges resulting from unconfined disposal operations (such as beach nourishment or other beneficial uses); discharges from confined disposal facilities which enter waters of the United States (such as effluent, surface runoff, or leachate); and overflow from dredge hoppers, scows, or other transport vessels.

Effluent - Water that is discharged from a confined disposal facility during, and as a result of, the filling or placement of dredged material.

Emergency - In the context of dredging operations, emergency is defined in 33 CFR Part 335.7 as a "situation which would result in an unacceptable hazard to life or navigation, a significant loss of property, or an immediate and unforeseen significant economic hardship if corrective action is not taken within a time period of less than the normal time needed under standard procedures."

Federal Project - Herein, any work or activity of any nature and for any purpose that is to be performed by or for the Secretary of the Army acting through the Chief of Engineers pursuant to Congressional authorizations. It does not include work requested by any other Federal agency on a cost-reimbursable basis.

Federal Standard - The dredged material disposal alternative or alternatives identified by the US Army Corps of Engineers that represent the least costly alternatives consistent with sound engineering practices and meet the environmental standards established by the 404(b)(1) evaluation process or ocean-dumping criteria (33 CFR 335.7).

Habitat - The specific area or environment in which a particular type of plant or animal lives. An organism's habitat provides all of the basic requirements for the maintenance of life. Typical coastal habitats include beaches, marshes, rocky shores, bottom sediments, mudflats, and the water itself.

Leachate - Water or any other liquid that may contain dissolved (leached) soluble materials, such as organic salts and mineral salts, derived from a solid material. For example, rainwater that percolates through a confined disposal facility and picks up dissolved contaminants is considered leachate.

Local Sponsor - A public entity (e.g., port district) that sponsors Federal navigation projects. The sponsor seeks to acquire or hold permits and approvals for disposal of dredged material at a disposal site (USACE 1986).

Major Federal Action - Includes actions with effects that may be major and that are potentially subject to Federal control and responsibility. "Major" refers to the context (meaning that the action must be analyzed in several contexts, such as the effects on the environment, society, regions, interests, and locality) and intensity (meaning the severity of the impact). It can include (a) new and continuing activities, projects, and programs entirely or partly financed, assisted, conducted, regulated, or approved by Federal agencies; (b) new or revised agency rules, regulations, plans, policies, or procedures; and (c) legislative proposals. "Action" does not include funding assistance solely in the form of general revenue-sharing funds where there is no Federal agency control over the subsequent use of such funds. "Action" also does not include judicial or administrative civil or criminal enforcement action.

Management Action - Those actions or measures that may be considered necessary to control or reduce the potential physical or chemical effects of dredged material disposal.

Mitigation - As defined in the Council on Environmental Quality's (CEQ) regulation 40 CFR 1508.20 (a-e), mitigation includes "Avoiding the impact altogether by not taking a certain action or parts of an action."

Open-Water Disposal - Placement of dredged material in rivers, lakes, estuaries, or oceans via pipeline or surface release from hopper dredges or barges.

Record of Decision (ROD) - A comprehensive summary required by the National Environmental Policy Act (NEPA) that discusses the factors leading to US Army Corps of Engineers (USACE) decisions on regulatory and Civil Works matters and is signed by the USACE District Engineer after completion of appropriate environmental analysis and public involvement.

Regulations - In the context of the Marine Protection, Research, and Sanctuaries Act, those regulations published in the Code of Federal Regulations, Title 40, Parts 220-227, and Title 33, Parts 209, 320-330, and 335-338 for evaluating proposals for dumping dredged material in the ocean. In the context of the Clean Water Act, refers to regulations published in the Code of Federal Regulations, Title 40, Parts 230, 231, and 233, and Title 33, Parts 209, 320-330, and 335-338 for evaluating proposals for the discharge of dredged material into waters falling under the jurisdiction of the Clean Water Act.

Runoff - The liquid fraction of dredged material or the surface flow caused by precipitation landing on upland or nearshore dredged material disposal sites.

Sediment - Material, such as sand, silt, or clay, suspended in or settled on the bottom of a water body. Sediment input to a body of water comes from natural sources, such as erosion of soils and weathering of rock, or as the result of anthropogenic activities, such as forest or agricultural practices, or construction activities. The term dredged material refers to material which has been dredged from a water body, while the term sediment refers to materials in a water body prior to the dredging process.

Suspended Solids - Organic or inorganic particles that are suspended in water. The term includes sand, mud, and clay particles as well as other solids, such as biological material, suspended in the water column.

Territorial Sea - The strip of water immediately adjacent to the coast of a nation measured from the baseline as determined in accordance with the Convention on the Territorial Sea and the Contiguous Zone (15 UST 1606; TIAS 5639), and extending a distance of 3 nautical miles from the baseline.

Toxicity - Level of mortality by a group of organisms that have been affected by the properties of a substance, such as contaminated water, sediment, or dredged material.

Toxic Pollutant - Pollutants, or combinations of pollutants, including disease-causing agents, that after discharge and upon exposure, ingestion, inhalation, or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, will, on the basis of information available to the Administrator of the US Environmental Protection Agency (EPA), cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions, or physical deformations in such organisms or their offspring.

Turbidity - An optical measure of the amount of material suspended in the water. Increasing the turbidity of the water decreases the amount of light that penetrates the water column. Very high levels of turbidity can be harmful to aquatic life (USACE 1986).

Upland Environment - The geochemical environment in which dredged material may become unsaturated, dried out, and oxidized.

Wetlands - Areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated-soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

Wetlands Restoration - Involves either improving the condition of existing degraded wetlands so that the functions that they provide are of a higher quality, or reestablishing wetlands where they formerly existed before they were drained or otherwise converted (Conservation Foundation 1988).

Zoning - To designate, by ordinances, areas of land reserved and regulated for specific land uses.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 1993	Final report

4. TITLE AND SUBTITLE Long-term Management Strategy for Dredged Material Disposal for Naval Weapons Station, Yorktown, Yorktown, Virginia; Naval Supply Center, Cheatham Annex, Williamsburg, Virginia; and (Continued)

5. FUNDING NUMBERS

Project Orders
N61414-89-PO-00020
N0018990P000001
N0010990WRPW314

6. AUTHOR(S)

See reverse.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

See reverse.

8. PERFORMING ORGANIZATION REPORT NUMBER

Miscellaneous Paper EL-93-1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Naval Facilities Engineering Command
Atlantic Division, US Navy
Norfolk, VA 23511-6287

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report is the second in a five-phase process designed to locate the most suitable sites for the long-term management of material dredged from three naval bases located in southeastern Virginia. These bases include the Naval Weapons Station, Yorktown, VA; the Naval Supply Center, Cheatham Annex, Williamsburg, VA; and the Naval Amphibious Base, Little Creek, Norfolk, VA. The long-term management strategy (LTMS) used in this process consists of evaluating existing management options, formulating the alternatives, performing a detailed analysis of the alternatives, implementing the LTMS, and conducting a periodic review and update of the LTMS. The purpose of such an LTMS is to provide a consistent, logical procedure by which alternatives can be identified, evaluated, screened, and recommended so that the dredged material placement operations are conducted in a timely and cost-effective manner.

This report provides an assessment of various open-water, confined, and beneficial-use disposal options. Based on the results of Phase II, recommendations are made for Phase III of the LTMS process.

14. SUBJECT TERMS

See reverse.

15. NUMBER OF PAGES

186

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

4. (Concluded).

Naval Amphibious Base, Little Creek, Norfolk, Virginia

6. (Concluded).

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7. (Concluded).

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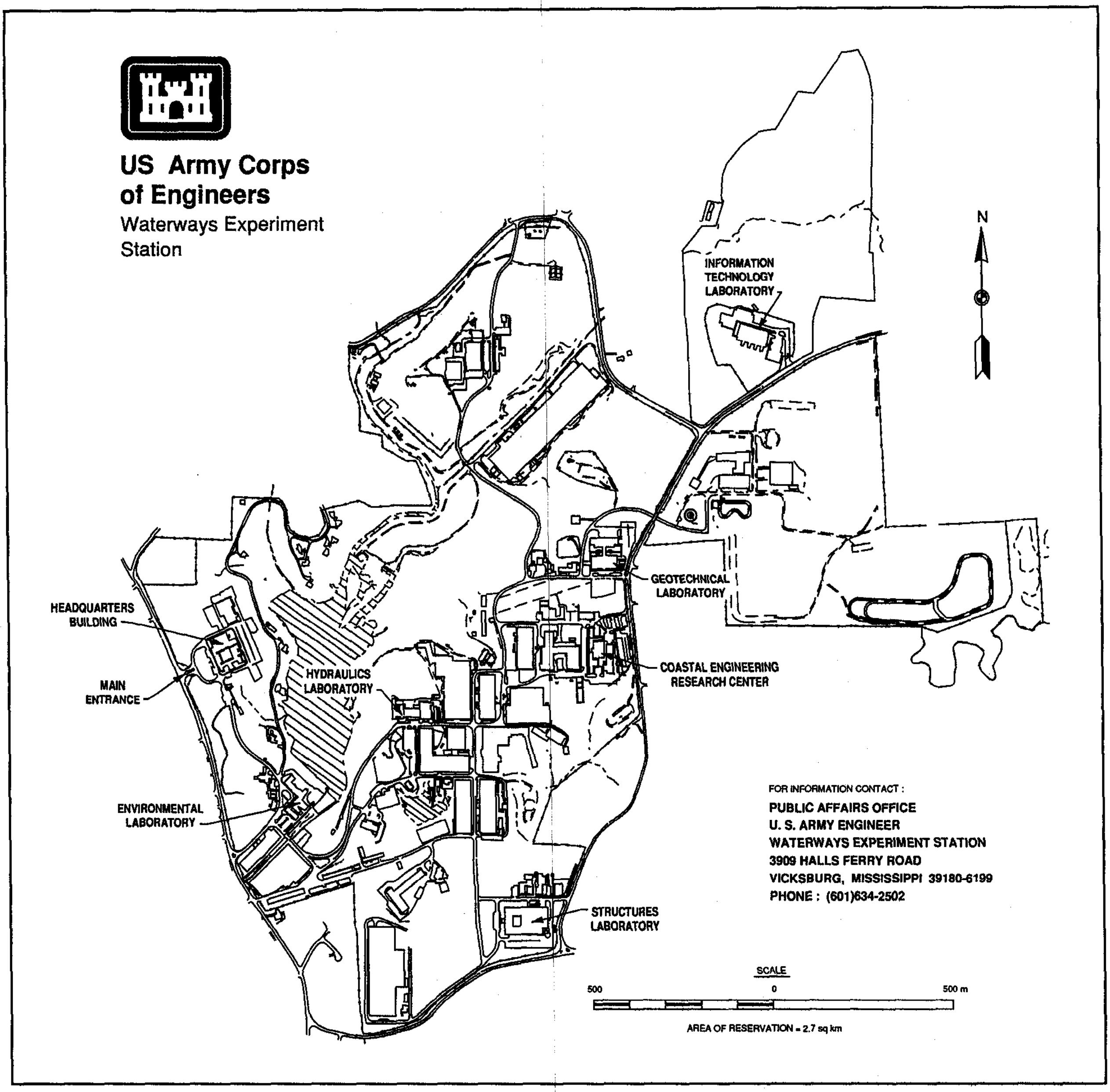
Vanderbilt University, Nashville, TN 37203

14. (Concluded).

Chesapeake Bay	Dredging	York River
Craney Island	Environmental resources	
Dredged material disposal alternatives	Long-term management strategies	



Waterways Experiment Station Cataloging-in-Publication Data

Palermo, Michael R.

Long-term management strategy for dredged material disposal for Naval Weapons Station, Yorktown, Yorktown, Virginia; Naval Supply Center, Cheatham Annex, Williamsburg, Virginia; and Naval Amphibious Base, Little Creek, Norfolk,Virginia. Phase II: Formulation of alternatives / by Michael R. Palermo ... [et al.] ; prepared for U.S. Navy, Atlantic Division, Naval Facilities Engineering Command.

186 p. : ill. ; 28 cm. — (Miscellaneous paper ; EL-93-1)

Includes bibliographical references.

1. Dredging — Environmental aspects — Virginia — Norfolk. 2 Dredging spoil — Environmental aspects — Virginia — Williamsburg. 3. Environmental engineering — Atlantic Coast Va.) 4. Naval Weapons Station (Yorktown, Va.) I. Palermo, Michael R. II. United States. Naval Facilities Engineering Command. III. U.S. Army Engineer Waterways Experiment Station. IV. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; EL-93-1.

TA7 W34m no.EL-93-1